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ABSTRACT

This volume contains 41 papers, 10 abstracts/research notes, and an after-dinner speech "The Book of Genesis and the Chronicles of the People of ASERA (Australasian Science Education Research Association). Paper titles include: "Improving students' understanding of carbohydrate metabolism in first-year Biochemistry at tertiary level"; "Students' learning in science lessons: towards understanding the learning process"; "Intention and practice in school science education"; "Teaching science in primary schools: what knowledge do teachers need?"; "Pre-service teachers' use of problem-solving in primary science"; "Group interactions in science practical work"; "Teaching portfolios: developing quality learning in pre-service science teachers"; "From science teacher to technology facilitator: a case study of Katherine"; "Progression in school science curriculum: a rational prospect or a chimera?"; "The development of a K-3 science profile in the context of the National Science Statement and Profile"; "Newton's Third Law after Newton"; "Concept substitution: an instructional strategy for promoting conceptual change"; "An examination of the predictions and explanations of pre-service nurses across a range of contexts involving the same principles of fluid physics: a preliminary study"; "Learning to learn in informal science settings"; "Technology education and science education: engineering as a case study of relationships"; "First-year tertiary students' understanding or iron filing patterns around a magnet"; "Application of genetics knowledge to the solution of pedigree problems"; "Student beliefs and learning environments: developing a survey of factors related to conceptual change"; "Subject competency of teachers and level of dependence on resource packs to teach levers, gears and pulleys"; "Explainers' perceptions of visitors' learning at an Interactive Science and Technology Centre"; "Technological problem solving in two science classrooms"; "Images in mirrors: recollections, alternative explanations and modes of cognitive functioning"; "Responses to an interactive science exhibit in a school setting"; "Diagram predication and higher order structures in mental representation"; "Perceptions of assessment in a senior physics class"; "Gender inclusive curricula: a focus on two responses"; "Knowing and learning about science in a preservice setting: a narrative study"; "Factors perceived to have enabled 25 women to develop expertise to teach primary science"; "The effect of the direction of motion on students' conceptions of forces"; "Measuring affective outcomes from a visit to a Science Education Centre"; "Students' thinking in a chemistry laboratory"; "Data handling in the primary science classroom: children's perception of the purpose of graphs"; "'Have you got any cholesterol?': Adults' views of human nutrition"; "A constructivist approach to secondary school science experiments"; "'I want to find out how the sun works!' Children's sociodramatic play and its potential role in the early learning of physical science"; "Narrative in the science curriculum"; "Comprehension of non-technical words in science: the case of students using a 'foreign' language as the medium of instruction"; "Children's interests in geology and biology"; "Consistency of children's use of science conceptions: problems with the notion of 'conceptual change'"; "Self-efficacy and science anxiety among pre-service primary teachers: origins and remedies"; and "Teacher professional development: which aspects of in-service do teachers believe influence their classroom practice?" (MKR)

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Selected refereed papers from the Twenty-fifth Annual Conference of the Australasian Science Education Research Association, organised by the University of Tasmania, Hobart, 10-13 July, 1994.

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EDITORIAL COMMENTS

This is a year of celebration for all of us who are involved in science education research in Australia and New Zealand. We have already held our 25th ASERA conference; next year, in May 1995, we could celebrate the 25th anniversary of the foundation of ASERA (except that we now meet in July!); and the next issue of Research in Science Education will be Volume 25. Readers may be a little puzzled at first over why all of these twenty-fives don't happen simultaneously. The reasons are partly semantic and partly historical. In everyday usage, a 25th anniversary occurs 25 years after the event, so that a couple married in 1970 will celebrate their 25th anniversary in 1995. Conferences, however, begin to be enumerated right from the start, so that ASERA's 25th conference occurred 24 years after it was founded.

As for the numbering of RISE, that is due to the fact that the first conference did not result in any publications: it was primarily a meeting of like-minded people who came to Monash, as a result of an invitation issued by Peter Fensham, to explore the possibility of creating a national science education research organisation. The first publication, called Research 1971, appeared after the second conference, held in Sydney; Dick Tisher was the founding editor. Two years later, the name changed to Science Education Research 1973. However, someone undoubtedly recognised the problem of a journal title that alters its name each year, and so in 1974, with Volume 4, the present title was adopted.

The 25th conference, the second to be held in Hobart, was a marvellous affair. Brian Jones and Max Walsh, with the backing of a professional conference company, did a superb job. (It may be a sign of my advancing age, but I found the comforts of a hotel to be a pleasant contrast to the rather spartan living conditions in one of the University of Tasmania's student colleges that we encountered at our previous conference in 1981.) ASERA participation keeps rising: this time almost 150 people came, not just from Australia and New Zealand, but from Singapore, Hong Kong, the Philippines, Fiji, South Africa and England as well. Three of the participants had also been present at the founding of ASERA: Peter Fensham (now retired from his chair at Monash but as active as ever), Dick White (described in Research 1971 as ASERA's "administrative assistant" and now Dean of Education at Monash) and myself. Ninety papers – a record number – were presented, and 72 of these, another record, were submitted for publication. (Unfortunately, the RISE budget does not stretch to cover the cost of publishing a 700-page journal, and we have had to be selective.)

This issue of RISE is the sixth that I have edited, and it will be my last. It is perhaps an appropriate time to reflect on the many changes that have taken place in the journal since Research 1971 first appeared 23 years ago. I have all of the issues on my shelf. The most immediately obvious change is in the external appearance: from a paper-covered, stapled booklet, through the red-covered editions, to our present format. The size has grown through the years: from eleven papers in 1971 to more than forty in recent years, from 146 pages to around 400. The technology of production has changed: manuscripts and electric typewriters have given way to word-processing, floppy disk versions, and laser printers. And in what is perhaps a portent of the future, the final version of Marilyn Fleer and Tim Hardy's paper was sent to me by email. The process of unscrambling the BinHex code, reading it into a Word for Windows file, and converting it to WordPerfect was completed within five minutes of its transmission from Canberra.

But these are mere technical details. The most significant changes are associated with the contributors and their contributions: who they are, and what they are writing about. The first ASERA contributors were frequently former secondary school teachers who had found new positions in the rapidly expanding university sector of the 1960s. The make-up of ASERA in the 1990s is very different. Federal funding of the tertiary sector in the 1970s, and the Dawkins amalgamation initiatives in the late 1980s, have resulted in a much wider range of people becoming involved in educational research activities. RISE papers now encompass science education research conducted in kindergartens, in primary schools, in secondary schools, in university undergraduate science courses, in initial and in-service teacher education, and in the wider, public world of hospitals, farms and museums. The journal is much the richer for it.

Editorial procedures have changed, too, as we have evolved into a proper journal. Dick Tisher's first effort in 1971 was essentially a one-man-show. The 1977 conference in Wagga Wagga saw the establishment of a small editorial board; for more than a decade, editorial boards acted informally, to provide advice to the editor about whether or not to accept a paper. The Perth conference in 1990 carried a policy decision: all papers were to be reviewed, independently, by two referees. In a development that reflects ASERA's strong commitment to democracy and co-operative endeavour, the Review Panel — now numbering ninety — contains a sizeable proportion of the ASERA membership. If a few of the names on the list (pp. viii - ix) appear unfamiliar, that is because I occasionally go outside ASERA to obtain the judgments of academics with particular expertise in subject-matter fields or research methods not always available within the organisation. This is an appropriate place to record my thanks to all of them for their competent, constructive and prompt reviews. At the same time, I want to acknowledge the considerable help during the past five years of the various deputy editors and of the office staff at Monash.

The next volume of RISE will reflect another major change in the evolution of this journal. In Perth in 1990, we first raised the possibility of publishing RISE as a conventional journal, with several issues per year, and not restricted to contributions from conference participants. That idea was adopted in Lismore in 1993, and Cam McRobbie at Queensland University of Technology offered to return to the editorship of the new expanded journal. (I say 'return', because Cam served as editor once before, in 1978, during a period in the late 1970s in which the journal was edited by someone from the city where the conference was held.) To prepare for his second coming, Cam has been assembling contributions throughout the past year, and Volume 25 Number 1 should appear early in 1995. Right now, Cam may not know what he has let himself in for, but he is certainly going to find out rather soon. This is an appropriate time to wish Cam, ASERA and the new RISE enterprise every success. Please give it your support.

Monash University
December 1994

Paul Gardner
Editor

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GUIDELINES FOR AUTHORS FOR THE PREPARATION OF PAPERS AND DISKS FOR RESEARCH IN SCIENCE EDUCATION

SUBMISSION TO CONFERENCE ORGANISERS

Hard copies only are required for submission to the ASERA conference organisers. Setting out can be in the same format as required for publication, or in some other format if you prefer.

SUBMISSION TO EDITOR FOR PUBLICATION IN RISE

Papers submitted to the editor for publication in RISE should be on disk, with three hard copies. See Word Processing and Setting Out below. Papers should be submitted as early as possible within the four weeks following the conference.

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Software We use WordPerfect 5.1, but other software is acceptable, as we have the facilities to convert other files.

N.B. It is the primary responsibility of authors to ensure that copy has been thoroughly proof read. Please ensure that typographical errors have been corrected, and that there is agreement between the references in the text and the final reference list.

Setting Out

Length Each paper is to have a maximum length of 10 pages in RISE format (approximately 42000 bytes). This length includes text, reference list and pages containing diagrams, figures and tables. This is a strict requirement and papers which exceed it will not be accepted for review. All pages are to be numbered consecutively. If you wish to see what your paper will look like in RISE format, set your format at 90 characters per line, single spacing, page number centred at top, followed by one blank line, and 50 lines of text. To make your own hard copy of this, you will need a small print font. We use Helvetica 9pt (AE)

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Mary Smith & John A. Smith
University of Central Australia Alice Springs College

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CORRELATIONS BETWEEN ANXIETY AND RUNNING SPEED

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Indented dot points Use asterisks, not letters, numbers, or dots to mark indented dot points, e.g. The project involved

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Fig. 3 A model of the learning process

Headings Main headings should appear in CAPITALS in the centre of the page. Sub-headings should be in lower case, underlined, and left-justified. They should be used at regular intervals to assist in the reader's comprehension of the text. Section and sub-section headings should not be numbered.

Footnotes are not to be used.

References References to journals and books should follow the APA guidelines. In the body of the paper references should appear, for example, as Bernstein (1971), or Fisher and Fraser (1983). References in parentheses are presented as (White & Tisher, 1986). These references should be placed in the reference list as follows:

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Fisher, D.L., & Fraser, B.J. (1983). A comparison of actual and preferred classroom environments as perceived by science teachers and students. Journal of Research in Science Teaching, 20, 55 - 61.
White, R., & Tisher, R. (1986). Natural sciences. In M.C. Wittrock (Ed.) Handbook of research on teaching (3rd ed.) New York: McMillan.

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DR MARY SMITH, Senior Lecturer, Faculty of Education, University of Central Australia, Alice Springs, NT 0870. Specializations: biotechnology curriculum development, biology teacher education.

Research in Science Education, 1994, 24, 1-10

IMPROVING STUDENTS' UNDERSTANDING OF CARBOHYDRATE METABOLISM IN FIRST-YEAR BIOCHEMISTRY AT TERTIARY LEVEL

Trevor R. Anderson & Diane J. Grayson
University of Natal

ABSTRACT

Many introductory biochemistry students have problems understanding metabolism and acquiring the skills necessary to study metabolic pathways. In this paper we suggest that this may be largely due to the use of a traditional teaching approach which emphasises memorisation rather than understanding. We present an alternative approach to teaching carbohydrate metabolism which is designed to promote understanding of pathways. The approach also enables regular monitoring of, and reflection on, student progress and the identification of student reasoning and conceptual difficulties through the use of specially designed problems. Preliminary results are presented giving examples of specific student difficulties and the extent to which they were addressed by the alternative instructional approach. A qualitative evaluation of the approach is also presented.

INTRODUCTION

The topic of metabolism is of central importance in the field of biochemistry. The vast majority of biochemistry curricula therefore include at least an introductory course in metabolism. In the Faculty of Science at the University of Natal the introductory biochemistry course, which includes a section on metabolism, is unusual in that it is attended by a large group of about 160 students at second-year level in which approximately 110 are non-majors, mainly from the Faculty of Agriculture. It has been our experience that many of the students in this course have problems understanding metabolism and acquiring the skills necessary to study metabolic pathways. Consequently, they are unable to apply the acquired knowledge and skills to their other life and agricultural science subjects. We believe that the failure of students to achieve acceptable levels of understanding of metabolism is mainly due to the use of a traditional teaching approach which involves extensive memorisation of metabolic pathways and chemical structures. This opinion is supported by some biochemistry educators who have proposed various instructional approaches for improving student understanding (Wood, 1989; Vella, 1993; Brosemer, 1989). An alternative teaching approach has therefore been introduced which emphasises understanding of the functioning of pathways in order to enable students to apply their knowledge to any metabolic problem that they might encounter in the future.

In this paper we will identify specific goals of the course, motivate for a change from a more traditional to an alternative teaching approach, and describe in detail how the instructional approach has been designed to meet the specified course goals. We will then describe the effect of the application of the alternative approach on a subset of introductory biochemistry students and evaluate the extent to which the approach made it possible to identify and reduce students' reasoning and conceptual difficulties and improve students' understanding of metabolism.

GOALS OF THE CARBOHYDRATE METABOLISM COURSE

It has been our experience that most introductory biochemistry curricula at universities are designed around the topics reflected in the contents pages of the prescribed text books. If the goals of the course were to expose students to as much information as possible about every major area of biochemistry, then it might be acceptable to design the syllabus around a good text book. However over the years, with the rapid expansion of the field of biochemistry, this approach has resulted in the inundation of students with more and more information at the expense of understanding, skill development and long-term learning.

For our carbohydrate metabolism course we decided that there was a need to articulate a new set of course goals that would answer the question: what would you expect students to learn/gain from an introductory course on metabolism? The suggested goals of the course, in summary, are that students should learn and understand:

1. the importance of metabolism in living organisms;
2. why, where, and how each pathway functions in cells;
3. how pathways interrelate within and between different tissues;
4. how the metabolic "machine" is regulated under normal/stress conditions;
5. the skills required to acquire knowledge and understanding of unseen pathways;
6. how to apply this expertise to the solving of real problems in their careers.

These goals emphasise the importance of giving students a holistic understanding of the functioning of metabolism, its real-life relevance, its usefulness and applicability to other areas of science and the cognitive and practical skills needed to study metabolism. Various biochemical educators (e.g. Wood, 1990; Brosemer, 1989) have reported similar objectives for their metabolism courses, while these goals are also in line with what cognitive scientists Resnick & Klopfer (1989) call a "thinking curriculum".

NEED FOR AN ALTERNATIVE INSTRUCTIONAL APPROACH

Two factors provided the motivation for introducing an alternative instructional approach. The first factor was based on experience by one of us (T.R.A.) of teaching biochemistry. A general sense of dissatisfaction was felt with past student performance, and the apparent lack of ability of most third year students to transfer metabolism concepts from introductory to third-year metabolism courses. It was also felt that such problems may be due, at least in part, to the instructional approaches practised in the Department of Biochemistry at introductory level, in which the emphasis is on teaching content. From a cognitive science perspective, the assumption made by many lecturers that content-driven instruction will automatically lead to the development of skills is suspect (Resnick, 1989).

The second motivating factor was the responses of post-graduate students to a questionnaire we administered in order to obtain their perceptions of the instructional approach, method of assessment and goals of the undergraduate biochemistry course. The students' responses to the questionnaire yielded some clear insights as to what they thought the goals of the course should be, how it should be taught and how students should be assessed. Whereas most of the 9 respondents felt that goals 1 and 2 were adequately achieved (78 and 100%, respectively), only 44 and 67% of students felt that goals 3 and 4, respectively had been achieved. This is a common problem in introductory biochemistry courses in which students often fail to integrate the knowledge they have acquired of each metabolic pathway, possibly because each pathway is usually taught as a module by a different teacher who may not promote transfer of knowledge between modules. The importance of integrating knowledge for improved understanding has been emphasised by Grayson (1992) who states that understanding is fundamentally about making connections between discrete pieces of knowledge, about placing in context. She proceeds to quote from Perkins, Crismond and Unger (1995) who argue that understanding consists of an explanation structure that is both extensible and revisable and manifests itself as a "rich network of explanatory relationships". Sixty-seven percent of students also felt that they had not been taught the necessary practical and cognitive skills (goals 5 and 6) required to acquire knowledge and understanding of any metabolic pathway that they might encounter, in order to enable them to apply their expertise to other related areas of science.

In response to a request to: "list other goals that you feel would be important to achieve", students emphasised the importance of conceptual understanding and the learning of relevant skills. The following two comments are illustrative of their opinions:

Student 1: Ability to link concepts and ideas so that more information is understood, appreciated and retained.
Student 2: ....skills to relate theory to practical....

When students were asked whether the teaching approach and method of assessment in their metabolism course had emphasised the importance of conceptual understanding, 64% responded negatively, while all students responded in the affirmative when asked whether their course had required excessive memorisation of pathways and structures. Seventy-eight percent of students also felt that the approach to teaching needed improving. When asked how they thought this could be achieved, the following two quotes are representative of their responses:

Student 1: ....more understanding of significance ....
Student 2: Test understanding rather than memory by asking applied questions;

Thus to summarise, our own teaching experiences as well as student responses to a questionnaire support our belief that the traditional approach employed for the teaching of introductory metabolism to biochemistry students has involved excessive memorisation at the expense of understanding of concepts and the integration of knowledge. In an attempt to improve the situation we introduced an alternative teaching approach, key features of which are described in the next section.

DESCRIPTION OF THE ALTERNATIVE APPROACH

The course structure and alternative instructional approach were designed in order to meet the goals described earlier. This involved the careful selection of course content, the use of instructional techniques designed to promote student understanding rather than memorisation, and the regular monitoring of, and reflection on, student progress.

In 1994 the carbohydrate metabolism section of the metabolism module lasted for four weeks and consisted of seventeen 45-minute lectures and three 1-hour tutorials. The metabolic pathways covered by the course included the pentose phosphate pathway, gluconeogenesis, glycogenolysis, glycogenesis, and glycolysis leading to ethanol or lactate production. The aerobic parts of carbohydrate metabolism, namely Krebs cycle and oxidative phosphorylation, are taught in a different module. The first three lectures were devoted to introducing students to the basics of bioenergetics with an emphasis on the applications of the first and second laws of thermodynamics to metabolic pathways. As will be shown later, a knowledge of thermodynamics is vital for the understanding of the workings of metabolic pathways. Since most of our students do not recall much of the thermodynamics that they studied the previous year in chemistry it was necessary to re-teach the relevant thermodynamic concepts in a manner that was understandable to students and which could be usefully applied to metabolism. In this regard, various workers (e.g. Nelsestuen, 1989; Abu-Salah, 1992; Brosemer, 1989) have published very useful papers on approaches to teaching thermodynamics to introductory biochemistry students. Brosemer (1989) takes the more unorthodox view that the approach to teaching thermodynamics should be totally qualitative. We have adopted this qualitative approach but also consider it important that students learn to do goal-orientated thermodynamic calculations for a more complete understanding of metabolism.

In accordance with the goals, the focus of the instructional approach was on helping students understand why, where, how, and to what extent the metabolic pathways function in an integrated manner, in the various tissues, and under different physiological conditions. The aim was to foster learning that would enable students to transfer and apply their knowledge and skills to any metabolic problem that they might encounter in the future. To help achieve this aim, the goals of the course were made explicit to the students, while the need for memorisation was minimised by always supplying students with handouts of relevant pathway details (including chemical structures where appropriate), even in the case of the examination paper. This practice has also been suggested by Wood (1990) who makes some excellent points on how to teach for improved understanding of metabolism. Every effort was also made to promote transfer of knowledge by informing students about how the pathways in our module related both to each other and to those covered in other modules. To stimulate thinking and interest, thought-provoking, challenging and relevant problems were presented to students and an interactive teaching approach was used, especially in tutorial classes where the class was divided up into three groups of 50-60 students and supervised by a lecturer and three demonstrators.

A crucial feature of the entire instructional approach was the design of problems designed to improve student understanding of metabolism which were pitched at the right level. Four types of problems were designed, involving:

1. the use of pulse-chase labelling and specific metabolic inhibitors to elucidate the identity and sequence of intermediates in a metabolic pathway;
2. the use of thermodynamics to study the energetics, efficiency, direction and regulation of reactions under normal and abnormal conditions;
3. the "removal", bypassing or inhibition of selected metabolic steps to gauge the importance of these steps to overall metabolism and the metabolic and physiological consequences of such treatments; and to use such "stress" effects to gain an integrated & holistic understanding of how each reaction plays a vital role in the metabolic "machine", the regulation and function of which in turn, enables organisms to be and stay alive;
4. the interpretation of unseen metabolic pathways, using a phased approached, to develop lasting analytical skills;

Some questions included a combination of more than one of these problem types. The problems were intended not only to stimulate student thinking and interest (see above) but also to help improve students' understanding and identify their reasoning and conceptual difficulties. Students' progress in overcoming these difficulties was monitored by comparing the incidence of a particular difficulty exposed by a certain problem type which was included in a pretest, quiz, test and examination. The purpose of problem type 1 is to expose students to typical techniques employed for studying and discovering metabolic pathways, many of which were used by the original pioneer workers in the field. By contrast, problem type 2 was designed to develop students' ability to use their knowledge of thermodynamics (especially the second law) to predict the behaviour of metabolic pathways under normal and abnormal (inhibited) conditions. This is an exercise that certain scientists and practitioners often have to go through when predicting the life-threatening effects of a genetic disease in humans or the excessive production of a biotechnologically important product by a bacterium. A detailed example of this approach is given in Fig. 1.

Problem type 3 was designed to impress upon students the essential nature of every reaction and reaction component for the correct functioning and integration of metabolic pathways. An example is Q5 in Fig. 1; another excellent example has been published by Chirpich (1982). Finally, the purpose of problem type 4 was to give students practice at applying their acquired knowledge to unseen pathways and thereby help develop problem-solving skills that are so essential for the work place. An example of the application of the alternative approach is presented in the next section.

APPLICATION OF THE ALTERNATIVE INSTRUCTIONAL APPROACH AND IDENTIFICATION OF STUDENT DIFFICULTIES

For the purposes of this study, we randomly selected a group of 40 students from the class of 160 students in introductory biochemistry. When problems of the types listed were given to the class in a pretest, test and/or in the examination, qualitative analysis of the group's answers revealed several reasoning and conceptual difficulties. For the purposes of this paper we will discuss three such difficulties in detail and present preliminary results indicating the extent to which students were able to overcome them during the duration of the course. We will also list other difficulties which were identified but not investigated further.

Fig. 1 outlines an example of a problem which revealed the three student difficulties referred to above. In this problem, the purpose of Q1 and Q5 was to improve students' understanding of the essential nature of all the reactions (and reaction intermediates) of a metabolic pathway (wherever inhibition may occur) which must be able to proceed in order for any measurable overall flux (or overall reaction rate of the pathway) to be detected. When students first had to answer problems of this type in a pretest, 83% of the students showed that they did not understand the above phenomenon. One manifestation of such a lack of understanding was apparent in student responses that indicated that the consecutive reactions occurring after an inhibited reaction in a pathway could continue to function (i.e., without any substrate). The following is illustrative of such a difficulty shown by two students answering Q1 and Q5 respectively:

Student 1:	[Iodoacetate] increases the overall flux because the pathway must compensate for a loss of an enzyme.
Student 2:	No lactic dehydrogenase simply means that pyruvate isn't converted to lactate, but this conversion is neither concerned with ATP production or consumption.

The incidence of the above problem improved to 70% in the semester test (three weeks later) while by the time they wrote the examination (a further two weeks later) only 43% of students showed any difficulties with questions of this type.

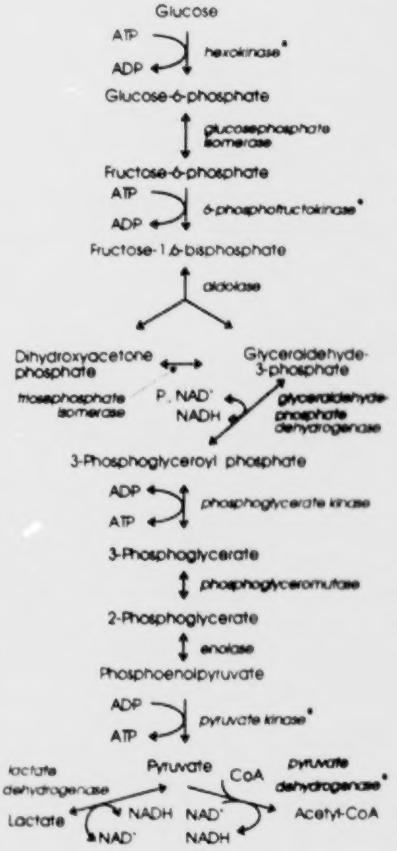
Q2 tests students' understanding of the second law of thermodynamics, in particular, near- and far-equilibrium and the reversibility of reactions. Students were expected to use the handout (which indicates the reversible nature of each reaction), and their knowledge of various thermodynamic parameters, especially the ratio of the equilibrium constant to the mass action ratio (35,000 for 6-phosphofructokinase), to predict which intermediates in glycolysis would accumulate due to iodoacetate inhibition. Questions of this type revealed a number of different conceptual difficulties with thermodynamics, with the incidence as high as

The discovery that glyceraldehyde-3-phosphate dehydrogenase is irreversibly inhibited by iodoacetate was important in the history of research on glycolysis. Explain the effect of this inhibitor in muscle on:

1. the overall flux through glycolysis;
2. the relative concentrations of intermediates of the glycolytic pathway;
3. the net production/utilisation of ATP by glycolysis and the pathway efficiency;
4. the synthesis of triacylglycerol;
5. If iodoacetate was able to inhibit lactate dehydrogenase instead of glyceraldehyde-3-phosphate dehydrogenase, would the muscle be able to generate ATP by glycolysis at a high enough rate for strenuous physical activity? Explain.

Brief solutions

1. Zero flux since only those reactions before the point of inhibition would occur.
2. The intermediates beyond the inhibitory point would slowly deplete. Due to iodoacetate inhibition and the irreversibility of the 6-phosphofructokinase reaction, glyceraldehyde-3-phosphate, dihydroxyacetone phosphate and fructose-1,6-bisphosphate would accumulate. Glucose, glucose 6-phosphate and fructose 6-phosphate would deplete slowly as available ATP for phosphorylation is depleted.
3. The pathway will be totally inefficient, since there will be a net utilisation of 2 ATP and no ATP production.
4. Accumulation of dihydroxyacetone phosphate stimulates (according to Le Chatelier's principle) its conversion, with glycerol phosphate dehydrogenase and NADH, to glycerol which reacts with fatty acids to yield triacylglycerols.
5. No, because the glyceraldehyde-3-phosphate dehydrogenase reaction would be inhibited by the failure of the lactic dehydrogenase reaction to supply it with NAD^+.


Glucose
ATP
ADP
hexokinase*
Glucose-6-phosphate
glucosephosphate isomerase
Fructose-6-phosphate
ATP
ADP
6-phosphofructokinase*
Fructose-1,6-bisphosphate
aldolase
Dihydroxyacetone phosphate
Glyceraldehyde-3-phosphate
triosephosphate isomerase
P$_i$, NAD$^+$
NADH
glyceraldehyde-phosphate dehydrogenase
3-Phosphoglyceroyl phosphate
ADP
ATP
phosphoglycerate kinase
3-Phosphoglycerate
phosphoglyceromutase
2-Phosphoglycerate
enolase
Phosphoenolpyruvate
ADP
ATP
pyruvate kinase*
Pyruvate
lactate dehydrogenase
Lactate
NADH
NAD$^+$
CoA
pyruvate dehydrogenase*
NAD$^+$
NADH
Acetyl-CoA

Note

All enzymes can function physiologically in the reverse direction except those marked with an asterisk.

Fig. 1. A typical problem and metabolic pathway handout
(June 1994 examination)

73% in the pretest. The following student answers to Q2 reflect two manifestations of such difficulties:

Student 1: The concentration of the intermediates .... won't be affected. Only the rate of the pathway will increase as they are all near-equilibrium reactions ....
Student 2: Fructose 1,6-bisphosphate concentration decreases since the production of this intermediate is inhibited by far-equilibrium reaction

Student 1 is confused between concentration and steady state kinetics, while student 2 does not understand the concept of far-equilibrium. During tutorials we made an effort to correct some of the difficulties with thermodynamics and found that the incidence of this problem improved to 60% in the test and 43% in the examination.

Q3 requires students to be able to understand how to calculate the energetics (ATP production) and the efficiency of the pathway. They need to realise that the efficiency of energy production can be significantly affected due to the fact that no reactions beyond the point of inhibition can occur (unless there is an alternative bypass route). Students' difficulties with bioenergetics problems of this nature showed an incidence of 53% in the pretest. Two different manifestations of this difficulty are illustrated in the following student answers to Q3:

Student 1: No effect on net production, however a decrease rate of pathway reactions does result in a decrease of the total amount of ATP produced during a certain time.
Student 2: ATP production will increase because the initial glycolysis stage [before the point of inhibition] will not be necessary.

Student 1 is not only unable to correctly calculate the net ATP produced/utilised but confused calculations of the net ATP per mole of glucose with the rate of production of ATP (i.e., kinetics). Student 2 not only has the calculation wrong and incorrectly thinks that the reactions after the inhibitory point can occur, but does not realise that the catabolism of glucose (the major substrate of glycolysis) is essential for the production of the intermediates, including ATP, in the latter part of the pathway. Difficulties with the concepts of bioenergetics appeared to be more easily overcome, with the incidence of this problem significantly improving first to 28% in the test and to only 5% in the final examination.

Thus to summarise, problems of type 2 and 3 (an example of which is in Fig. 1), enabled the identification of three major student difficulties:

- difficulties with understanding the essential nature of metabolic reactions;
- difficulties in understanding the concepts of near- and far-equilibrium and the reversibility;
- problems with understanding and calculating the bioenergetics of pathways. Clearly therefore, the alternative approach has exposed major student conceptual difficulties with thermodynamics which will be an important focus for future research. Indeed, misconceptions of this nature have been identified and studied by numerous workers both in the areas of chemistry and physics (Granville, 1985; Kesidou & Duit, 1993).

The types of problems listed earlier also made possible the identification of other conceptual or reasoning difficulties. Briefly, these were related to: the integrated nature of metabolic pathways (see Q4); the chemical properties of radioisotopes; the concepts of steady state concentration, relative thermodynamic stability, bond formation and fission, and denaturation; and the specific conventions used for drawing flow diagramme representations of metabolic pathways. It is noteworthy that most of these difficulties are chemical problems, suggesting that students might be inadequately transferring chemical concepts from first year chemistry studied in the previous year.

EVALUATION OF THE ALTERNATIVE APPROACH

The introduction of the alternative instructional approach invoked a wide range of reactions and comments from students and colleagues, as well as the external examiner for the introductory biochemistry examination. The external examiner wrote the following assessment of the examination questions and the performance of the students (G.K. Campbell, personal communication):

> The paper was an interesting one, and particularly in the open-ended nature of the questions in Section B [i.e., our questions]. The student answers were revealing, and quite challenging to mark. One hopes that the members of the class will remember enough of the examination for them to correct their misconceptions by reading and discussion. Before reading these questions I had wondered about methods for the application of the constructionist [constructivist] approach to biochemistry teaching.

In an anonymous evaluation administered to students at the end of the course, many students were equally enthusiastic and complimentary about the alternative teaching approach. Examples of students' comments are:

Student 1:	I strongly feel that the lecturer's approach will benefit students in the long run.
Student 2:	The overlap [with other fields] helps us relate one subject to another.
Student 3:	...interesting and, as far as I'm concerned, the most beneficial part of the Biochemistry course.

An indication that the problems in the course were challenging is illustrated by the following statements by a colleague and a student:

Colleague:	I don't think that I could answer this paper myself.
Student:	The lecturer expects students to go beyond what is taught [and] expects us to think like a 3rd/4th year biochemist.

This student comment also reflects the signs of insecurity shown by certain students when asked to think and reason things out instead of regurgitating facts. This problem diminished however with time as a result of more problem-solving practice and greater teacher interaction, which led to a general improvement in confidence.

Thus to summarise, student and peer opinion suggests that the alternative approach has been generally well received and is both beneficial and challenging for students.

DISCUSSION AND CONCLUSION

In this paper we have introduced an alternative approach for the teaching of carbohydrate metabolism which has been designed to reduce the necessity for excessive rote learning, focussing instead on promoting understanding of the functioning of metabolic pathways and the skills for studying them. In an attempt to improve student understanding we have identified specific course goals, designed problems aimed at achieving the goals and engaged in a process of monitoring and reflecting on the progress made by students.

Although many people consider the alternative approach to be successful, we feel that the ultimate value of any teaching approach is determined by the extent to which student understanding, performance and long-term learning are improved. In this regard we have already discussed the significant progress made by students in overcoming various conceptual and reasoning difficulties and thereby improving their overall understanding of metabolism. In addition, the overall average mark (for the carbohydrate metabolism section) of the study group improved from failing marks of 39% for the pretest and 47% for the test, to 54% for the examination. "Hidden" within these data was evidence of some outstanding progress made by certain students. For example, one student improved from a mark of 50% in the pretest to 95% and 94% in the test and examination, respectively. Other students showed improvement figures of 18%, 52% and 74%; 25%, 33% and 69%; and, 20%, 33% and 70%. Thus preliminary evidence suggests that the alternative approach is indeed improving student performance, but further studies are required in order to establish its full potential.

In conclusion, it is perhaps appropriate to quote a profound statement made by one of the postgraduate students:

> Student: If students are inspired, excited and challenged, everything is easier- i.e., motivate interest.

We feel that students should take more than a pass mark away with them. Ideally they should leave the course with good understanding of the subject, some long-lasting learning and having thoroughly enjoyed the challenge and the whole study experience. Indeed, judging by the enthusiastic responses and interest shown in tutorials (students often stayed over time without realising it) and the challenging questions students which succeeded in solving, we feel that our alternative teaching approach is meeting these objectives.

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STUDENTS' LEARNING IN SCIENCE LESSONS: TOWARDS UNDERSTANDING THE LEARNING PROCESS

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ABSTRACT

Constructivist views of learning have been applied to science education largely as a response to attempts to understand the origins of students' misconceptions in science, and therefore the learning process. As part of this effort to understand learning in science lessons, Appleton (1989) proposed a learning model drawn mainly from Piagetian (1978) ideas and generative learning theory (Osborne & Wittrock, 1983). This paper explores the development and evolution of the learning model as other constructivist views were applied, and as the model was tested against students' responses in science lessons. The revised model finally arrived at is then examined. It was found to be a useful means of describing students' learning processes during a science lesson.

INTRODUCTION

Attempts in recent years to understand the origins of students' misconceptions in science and by implication, the learning process in science lessons (see Pfundt & Duit, 1991 for a comprehensive bibliography), have led to the application of constructivist views of learning to science classrooms (Freyberg & Osborne, 1985; Tobin, 1990). Early emphasis was placed on the constructs and processes seen to be internal to the learner (Freyberg & Osborne, 1985), but more recently the significance of the social context has been emphasised (O'Loughlin, 1992; Tobin, 1990). Some years ago, Appleton (1989) proposed a learning model for science education drawn largely from Piaget (1978) and Osborne and Wittrock (1983). This paper describes a later version of the learning model resulting from consideration of other constructivist views of learning and classroom trials (Appleton, 1993a). The final model proved an effective means of following the learning progress of students during science lessons.

THE BEGINNING

A learning model based on selected constructivist views (Osborne & Wittrock, 1983; Piaget, 1978) was proposed and explored in terms of Year 6 students' investigations into the topic *Floating and Sinking* (Appleton, 1989). For a full explanation of the model see Appleton (1989). This model highlighted the importance of the learner's existing ideas in determining which schema were recalled and used to make sense of a learning situation, and the possible pathways a learner might take during a lesson, based around Piaget's notion of disequilibrium. While this was a simplified representation of the learning process, it formed a powerful basis for making decisions about science teaching (Appleton, 1990a, 1993b).

FURTHER THEORETICAL DEVELOPMENT

This initial learning model underwent considerable revision as a number of other aspects of constructivism were included. These involved theoretical considerations from Kelly (1955), Claxton (1990), Carey (1985), Bruner (1985), Bruner and Haste (1987), and Festinger (1957). In the initial model, the importance of the learning context was not emphasised (Claxton, 1990, Kelly, 1955) sufficiently, particularly with respect to its influence on the selection of memories to be recalled in response to the learning encounter. That students might opt out of learning, or rote learn answers was also presented in a very narrow framework in the initial model. From Kelly and Claxton, a more general basis for understanding why students might take these actions was identified. For instance, these reactions could be seen as learned responses to the learning context, based on past experiences of trying to cope with the demands of lessons. Bruner (1985) showed, using Vygotsky's (1978) work, the importance of the social context. The social circumstances of the learning context were therefore identified as an area under-emphasised in the model. Bruner also discussed the significance of language, a part of the social context, for achieving cognitive change through the process of scaffolding. Scaffolding occurs when the teacher identifies a child's current understanding of a concept, and by a sequence of questions and statements, helps the child reach a deeper understanding which is mutually constructed by child and teacher. This aspect was not evident in the model.

Another shortcoming of the model was identified from Festinger's *Cognitive Dissonance Theory* (1957). When the state of disequilibrium (dissonance in Festinger's terms) is reached, he suggested that a common response is for people to seek further information. Consequently an information seeking phase could be expected as an intermediate step prior to accommodation being reached. To a limited extent, this incorporated Bruner's idea about scaffolding as well. Dissonance theory also introduced the notion that a learner may not perceive the learning encounter as relevant and therefore ignore it altogether. Further, it showed that there were multiple pathways possible in the model, rather than the initial simpler pathways portrayed.

As well, closer analysis of Piaget's (1978) discussion of disequilibrium and accommodation introduced the possibility, not considered earlier, that an open-minded state may be achieved as a result of cognitive restructuring. That is, two ideas might be held juxtaposed by the learner, and no choice made between them.

A revised model incorporating all these theoretical positions was developed. This made the model more comprehensive, but at a cost of introducing greater complexity.

A TRIAL OF THE REVISED MODEL

Since the revised learning model was based on theoretical constructs, it was tested in several science lessons to ascertain how well it allowed students' progress through a lesson to be documented. The model had as its basis the notion of cognitive conflict generated from an encounter experienced by a student, so a lesson which began with a phase designed to generate cognitive conflict was used. A discrepant event (Suchman, 1966), where the students are confronted with an unexpected outcome from an experiment, was chosen from several suggested by Suchman and others (Friedl, 1986; Liem, 1987). In three classes of eleven year-olds, the discrepant event was presented in different ways, such as using a teacher demonstration and student activity in small groups. A group of four students in each class was videotaped, and each student interviewed after the lesson using the videotape to stimulate their recall of their thinking during the lesson. The videotapes and transcriptions of the interviews were used to map the students' progress on the learning model, during the lesson. The students' cognitive processes were inferred inductively from the data, and then matched to the model.

Results of the trial

It became obvious as the trial progressed that the model as revised was inadequate, and could not document many aspects of the students' thinking and learning processes during the lesson. This necessitated a further revision of the learning model to account for the observations and inferences about the students' thinking. The newly modified model retained the essential features of the earlier theoretically derived model, but was redrawn to simplify the visual appearance of the model and to incorporate the issues identified in the trials. It still portrayed the student's learning progress as essentially a linear sequence. While this was obviously not the case in the trials, it was accepted as a limitation of the model.

FURTHER TRIALS OF THE LEARNING MODEL

The newly modified learning model was subjected to a series of further trials to test the accuracy of its representation of a student's learning progress during a science lesson. The trials were conducted in a similar manner as before, with three classes of 12 to 13 year-olds. Three different discrepant events were used with each class this time, resulting in nine lessons. Two students from each class were interviewed after each lesson, and their progress through the learning model inferred from the interview and videotape data.

Results of the second trial

This third version of the learning model proved to be robust, and allowed adequate descriptions of students' learning progress during the observed lessons in the trials. Although the learning model was now able to be used to document the students' cognitive progress during the lessons observed, some problems were still experienced in using the model, particularly in three areas. The first was in relation to the types of information used by students. The three incorporated into the model (the teacher providing the answer, engaging with the encounter, and consulting books and peers) were not sufficiently comprehensive. For example, it was found that students used contextual cues from the lesson and the teacher's behaviour as information sources. A student, Denise, reported how, in a lesson, she deduced a possible answer to the discrepant event from the questions the teacher did not ask. Other cues used were the content from previous lessons, and non-verbal signals from the teacher.

The second problem area identified with the model was related to the influence of the attitudes, feelings and expectations of the students during the lesson. Aspects of these were implied in the overall social context in which the model operated, but they were found to influence the students' responses (for example, see Appleton, 1993a, 1993b) to such an extent that they needed to be made more explicit. The third problem area was to do with the structural organisation of the model. The only pathways represented after information was obtained were confusing and not clearly or logically portrayed. For example, during a lesson, it was noted that students continuously evaluated information, and used it in different ways depending on the information and the context at the time. The type of information processing which occurred varied between students, but even the same student would process information differently during different parts of the lesson. Such diverse pathways were not easily shown on the model. As well, the model had become very complex, and needed to be simplified.

THE FINAL MODEL REVISION

To revise the model, either minor changes could be made to incorporate as many of the above problem areas as possible, or the model could be totally restructured, particularly with a view to simplifying its structure. Although a minor restructuring was considered, the model was totally reorganised, as shown in Fig. 1. During the major restructuring, a further theoretical construct to differentiate between levels of cognitive processing was considered a useful addition, as different levels of processing had been evident in the students' responses. At a simple level, notions of surface and deep processing (Biggs, 1987; Biggs & Moore, 1993) provide a suitable distinction. Biggs described three approaches to learning in tertiary and secondary students: the surface approach, deep approach and achieving approach. Students

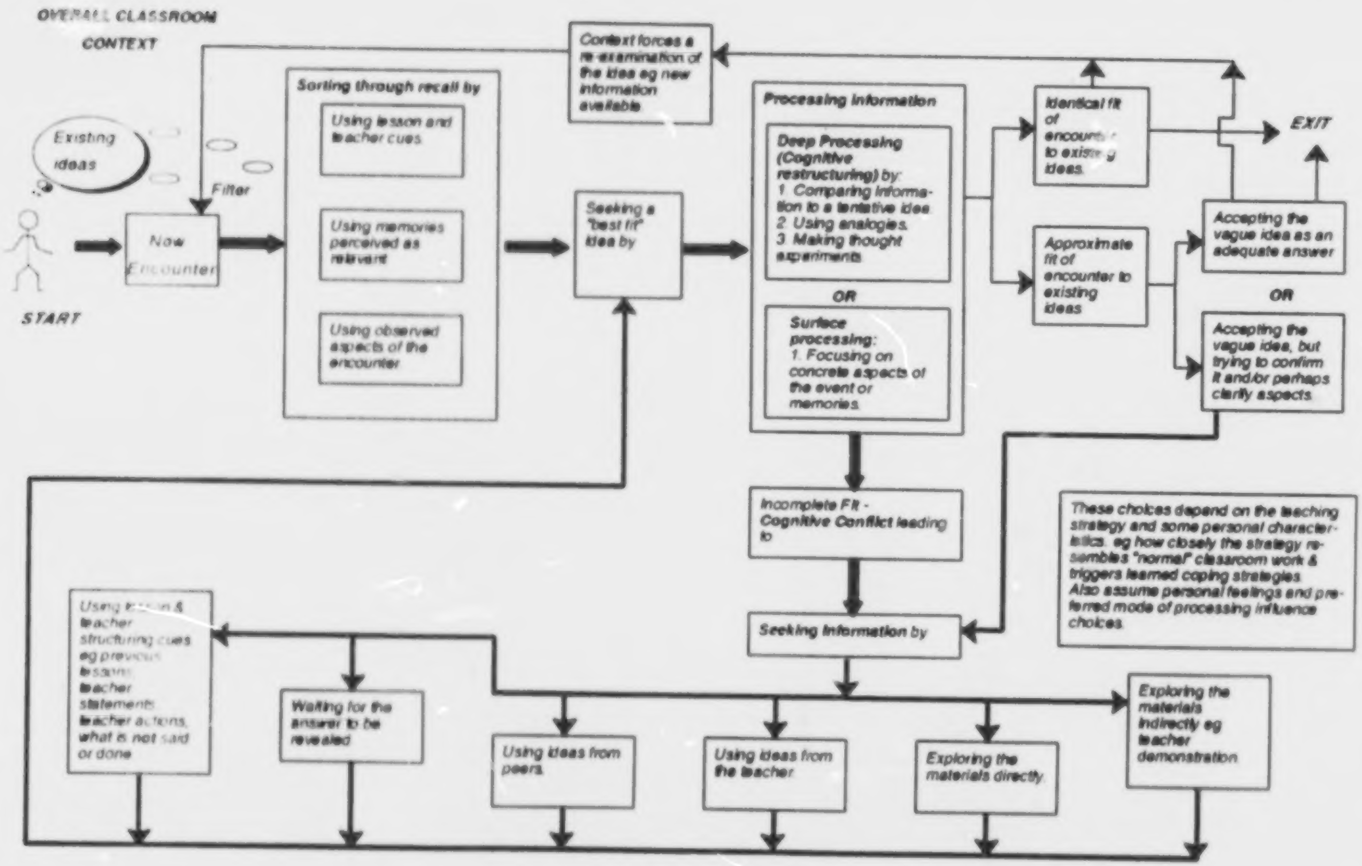
OVERALL CLASSROOM CONTEXT
Existing ideas
Filter
START
Now Encounter
Context forces a re-examination of the idea eg new information available
Sorting through recall by
Using lesson and teacher cues
Using memories perceived as relevant
Using observed aspects of the encounter
Seeking a "best fit" idea by
Processing information
Deep Processing (Cognitive restructuring) by:
1. Comparing information to a tentative idea.
2. Using analogies.
3. Making thought experiments.
OR
Surface processing:
1. Focusing on concrete aspects of the event or memories.
Identical fit of encounter to existing ideas.
Approximate fit of encounter to existing ideas
EXIT
Accepting the vague idea as an adequate answer
OR
Accepting the vague idea, but trying to confirm it and/or perhaps clarify aspects.
Incomplete Fit - Cognitive Conflict leading to
Seeking information by
These choices depend on the teaching strategy and some personal characteristics. eg how closely the strategy resembles "normal" classroom work & triggers learned coping strategies. Also assume personal feelings and preferred mode of processing influence choices.
Using lesson & teacher structuring cues eg previous lessons; teacher statements, teacher actions, what is not said or done
Waiting for the answer to be revealed
Using ideas from peers.
Using ideas from the teacher
Exploring the materials directly.
Exploring the materials indirectly eg teacher demonstration

Fig. 1. The revised learning model.

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who use the surface approach try to avoid both working toc hard, and failing in assessments. The main strategy employed is rote learning, where students focus on what appear to be the important points, and try to reproduce them. Those who use the deep approach are intrinsically motivated, and are interested in the task. They use strategies to help them understand the task, such as trying to relate it to what they already know, and deriving hypotheses to explain it. The motivation for students using the achieving approach comes from "the ego trip that comes from achieving high marks" (Biggs & Moore, 1993, p. 313). They choose strategies which will give the best rewards from the teacher and the highest marks, so strategies will vary depending on the task and situation. There is always an element of efficiency in their choice, which can involve either deep or surface approaches.

To simplify the model, it was considered necessary to omit portions which were not evident in any of the trials. The restructured model in Fig. 1 shows only one exit, and caters more readily for the iterative nature of cognitive processing during a lesson. The model still has limitations in that the contextual social aspects are represented in a limited way. For example, Biggs' (1987) *Achievement* orientation is not directly represented on the model, yet it is the student's desire to achieve which, in part, determines whether deep processing or surface processing occurs. The final revised version represents cognitive processing pathways in science lessons, rather than a general learning model.

An explanation of the model

The whole process described in the model is influenced by the *Overall Classroom Context*, and in particular, the student's perception of that context. Student bring to the classroom their own set of ideas, feelings and so on. A *New Encounter* such as a discrepant event causes students to sort through memories to recall those perceived as relevant. The (non-conscious) choice of memories is influenced by the students' *Existing ideas*, their perceptions of the *Classroom Context*, consequential *Observed aspects of the encounter* and *Cues provided by lesson and teacher*. Each student tries to arrive at a *"Best fit" idea* by processing the information from all these sources. The type of processing which occurs depends on the students' *Existing ideas* and abilities in processing, their perceptions of the demands of the *Overall Classroom Context*, and the level of challenge (interest and cognitive demand) presented by the *New Encounter* (Baird, 1992). If the students' perception of the school situation is such that they wish to achieve at school, and they have the ability (part of the *Existing ideas* cognitive structure) to perform *Deep Processing*, then they can choose the most appropriate type of processing for the situation as they perceive it. Students without the ability for *Deep Processing* have no alternative other than to use *Surface Processing*.

Following the *Processing of information*, there are three possible pathways. In the first, the students would consider that they have found an *Identical fit of the encounter to existing ideas*. The most likely consequence is for such students to *Exit* the learning process, believing that they know what is being taught. However, it is possible that, if they attend to continuing parts of the lesson, they encounter some new information which forces them to *Re-examine the idea*. This effectively constitutes a *New Encounter* for such students, and the process begins again.

In the second pathway, students might find that the *Encounter makes an approximate fit with existing ideas*. That is, many aspects of the vague or tentative idea may appear similar, although there might be some differences. Some students may then assume that the similarities are sufficient to allow the *Vague idea to be accepted as an adequate answer*. They would therefore *Exit* the learning process, or may later *Re-examine the idea* as described earlier. Alternatively, students may *Accept the vague idea* as a possible answer, but try to confirm it or clarify aspects of the idea which appear unclear. Students who do this would join those who took the third pathway by *Seeking Information*.

In the third pathway, students would find themselves in an *Incomplete Fit* state, with resultant *Cognitive Conflict*. A consequence of *Cognitive Conflict* is for students to *Seek Information*. In a classroom situation, there are many sources of information, but access to these is controlled by the *Classroom Context*, and in particular, the teaching strategy used by the teacher. Each teaching strategy has associated with it a particular physical and social setting (Appleton, 1993a) which may open some sources of information, but close others. Students' willingness and ability to use available information sources also depend on the *Classroom Context*. Students may have learned particular personal strategies for coping with some classroom contexts which they find boring or threatening, and these may be automatically "triggered" by a similar context (Appleton, 1993a). The coping strategy used may well prevent students from accessing some information even if it is available to them.

The possible information sources available in classroom contexts are:

> **Exploring the materials associated with the New Encounter indirectly.** If the encounter were presented as a teacher demonstration, for example, then the students' exploration would be limited to visual experiences mediated by the teacher's actions and words.
>
> **Exploring the materials associated with the New Encounter directly.** This is only possible in a hands-on type of lesson, whether organised as individual work, small group work, or students taking turns at manipulating the materials. Other materials such as books or audiovisual material may be explored if available.
>
> **Using ideas from the teacher.** The teacher usually talks fairly constantly in most lesson types, so this is a common source of information. The teacher-talk may be supplemented by other forms of communication such as non-verbal cues, teacher-prepared notes, chalk board summaries and the like.
>
> **Using ideas from peers.** In some lesson contexts, student talk is permitted. Such talk may be directed at the teacher, or may be student to student, depending on the teaching strategy used. In most classes, there are students who are recognised by peers as knowledgeable, and who are seen as useful sources of information. Information can, of course, be obtained from any student who contributes verbally, but the information offered by those with status as "clever" tends to be valued more highly (Appleton, 1993a).
>
> **Waiting for the answer to be revealed** is sometimes the only means of obtaining information which is available to students. This is again determined by the teaching strategy and *Classroom Context*. In such contexts, it is usually the teacher who ultimately reveals the answer - either directly, or indirectly from other students or books. It seems that an implicit "rule" of schooling understood by both teachers and students is that if the students are unsuccessful at finding an answer, then the teacher will ultimately reveal it. In some contexts, this may be a valid and efficient means for students to obtain information.
>
> **Using teacher and lesson structuring cues.** All teachers structure their lessons in logical ways to maximise student learning. Students aware of this can use such structuring as an information source. For example, if the previous lesson dealt with air pressure, then "the answer" to the current lesson might have something to do with air pressure. Other more subtle cues can be provided by the teacher simply by what he/she says, does, and does not say. For example, if students are engaged in a laboratory investigation using batteries, instructions to attach a wire and bulb to the

battery might be interpreted by a student unaware of the purpose of insulation on wires that no electric current is flowing in the wire, because the teacher would not tell them to do something unsafe.

Using information from any number of these sources, the students then *Seek a "best fit" idea* by *Processing the Information*, using either *Deep Processing* or *Surface Processing* or both. The cycle begins again, and continues until the lesson ends and/or the students *Exit* with either an *Identical Fit* or an *Approximate Fit*. Implicit in the model is the assumption that all students will exit the lesson with some notion of at least an *Approximate Fit*. The possibility exists, however, that some students may finish the lesson totally confused, with no idea of an answer. Since the model was attempting to portray cognitive processing in lessons, it was considered simpler to omit on the model any exit associated with little or no cognitive processing.

Some examples

To exemplify how the learning model was used, the classroom actions and learning progress of two students through the model are outlined below. The phrases in italics refer to sections of the model.

The first student, Denise. The discrepant event used in this lesson was adapted from *The Diving Bottle* (Suchman, 1966). A small glass bottle was upturned in a tall glass cylinder of water, and adjusted so that it only just floated. A sheet of rubber was fastened over the top of the cylinder, and pushed gently. The bottle sank to the bottom of the cylinder, and remained there even when the rubber sheet was removed. When the rubber sheet was pulled upwards gently, the bottle rose to the surface. The discrepant event was introduced as a teacher demonstration with explanations of the materials, and presented with an air of mystery: "I wonder what's going to happen?" (after Liem, 1987). The teacher explained the event using the materials as an aid, and drew the students' attention to key observations. Examples which the students could relate to were provided. The teacher involved the students in working through ideas using a normal classroom interaction pattern (teacher question — student response — teacher response). All student interaction was directly with the teacher, with no student-student discussion.

A student in the class, Denise, was interviewed after the lesson and her progress through the learning model during the lesson inferred. When the discrepant event was presented as a *New Encounter*, Denise *Sorted Through Recall* to find appropriate memories to help make sense of the event. The lesson and teacher cues, what she noticed about the event, and the memories she retrieved were *Processed at a Deep Level*, as Denise is highly *Achievement* oriented. Although she retrieved some possible schema which might provide an explanation for the discrepant event, she failed to reach an adequate explanation for what was happening. She therefore moved rapidly to an *Incomplete Fit* state, and began *Seeking Information* which may help her clarify the ideas which she was entertaining as possibilities. To do this, she *Explored the Materials Indirectly* from where she sat, and *Used Ideas from the Teacher* extensively, and to a lesser extent, *Ideas from Peers*. The information obtained was used to *Seek a "best fit" Idea* by further *Deep Processing*. This *Cognitive Restructuring* led her to an *Approximate Fit of an Idea* in which she had confidence as an explanation for the discrepant event. She *Accepted this Vague Idea, But Tried to Confirm It* by *Seeking further Information*. She used the same means of obtaining information as before, also drawing on *Lesson and Teacher Structuring Cues*. The process of scaffolding which the teacher engaged in was of particular help to her (but is not shown specifically on the model). The new information was again processed by *Restructuring of Ideas*. This restructuring and information seeking became an iterative process, with Denise gaining information, processing it and making predictions which were in turn confirmed by information obtained from the teacher and other sources. By the end of the lesson, she felt she had reached an *Identical Fit of the Encounter to her Restructured Ideas*, and therefore concluded with her initial ideas changed.

The second student, Colin. The discrepant event for this lesson was based on the *Double Pendulum* discrepant event (Liem, 1987; Suchman, 1966). A long piece of wooden dowel was placed horizontally across two clamps about 50 cm above the bench, so that the dowel could roll freely back and forth. Two simple pendulums of the same length and weight were then suspended from the dowel, about 15 cm apart. One pendulum was set in motion. In a short time, the second pendulum began swinging as well. Before long the first pendulum had almost stopped, while the second swung in full arcs. However, within a few minutes the first pendulum again picked up its amplitude of swing, while the second diminished. The discrepant event was conducted by small groups of four students working with their own materials, following the verbal instructions of the teacher along the lines suggested by Friedl (1986). After conducting the discrepant event a few times, the students noticed that the dowel rolled backwards and forwards slightly. Following the teacher's suggestions, they examined the effects of changing various variables, such as altering the number of washers in the pendulum bob, clamping the ends of the dowel, shortening the pendulum length, and the changing the amplitude of the starting swing. Within the group and as a whole class, they tried to develop an explanation for the event.

Colin, a member of one group, was videotaped during the lesson and interviewed afterwards. While the discrepant event was being conducted, he *Sorted Through Recall* by observing aspects of the encounter and linking to memories perceived as relevant. He *Sought a Best Fit* by *Deep Processing of Information*, but was unable to find a satisfactory explanation. By the end of the first experience of the discrepant event, he had reached an *Incomplete Fit* state, and began to *Seek Information*. He did this as part of the group, by *Exploring the Materials Directly*, and by watching others in the group (that is, he *Explored the Materials Indirectly*). He also *Used Ideas from his Peers*, particularly when some one noticed that the rod was moving on the clamps. He interpreted this movement as a sliding motion, and *(Surface) Processed the New Information* to arrive at an *Approximate Fit*. He was satisfied that this was an adequate explanation, so *Accepted the Vague Idea as an Adequate Answer*.

However, as others in the group challenged his assertion that the dowel was sliding, Colin was forced to *Re-examine the Idea*. The information that the dowel was rolling rather than sliding served as a *New Encounter* for him, causing him to search for other *Memories Perceived as Relevant*, *Process the Information* and again arrive at an *Incomplete Fit* state. As the group explored the variables influencing the event under the guidance of the teacher, he continued to *Seek Information* through the materials, peers, and teacher structuring cues. He used *Deep Processing* to arrive at another *Approximate Fit* (His idea was that wind from the moving pendulum caused the second to move), which he again *Accepted as an Adequate Answer*. When his group tested this idea by placing a sheet of cardboard between the pendulums, he again *Re-examined His Idea* and went through to an *Incomplete Fit* again.

Colin repeated his cycling through several ideas as his group continued to test effects of changing the various variables. When the effect of the rolling motion of the dowel was tested by clamping its ends, he accepted this as an *Approximate Fit*, but continued to *Try to Confirm/Clarify the Idea* by *Seeking Further Information*. Some clarification of the idea occurred late in the lesson, but he was unable to conclude with an *Identical Fit* situation. He recognised that his explanation was an *Approximate Fit*, but had to *Exit* at the end of the lesson with the *Vague Idea as an Adequate Answer*. However, during the lesson, there had been several occasions when he had been involved in Cognitive Restructuring through *Deep Processing*.

CONCLUSION

The restructured learning model is the outcome of both theoretical considerations and trials in a number of science lessons. The trials included both teacher demonstrations and small group activity lessons, but were confined to lessons which included a discrepant event. The model has been demonstrated as useful in identifying students' cognitive progress through science lessons of this type. Given that the learning model evolved through a process similar to action research with an experienced teacher and science educator constructing the theory of the model from the research and his own professional knowledge, it could be applied with some confidence to other lessons (Baird, 1992).

Knowledge of students' learning progress during lessons can provide teachers with a powerful aid to planning and diagnosis of learning problems. The initial version of the learning model represented by Figure 1 was used to devise and evaluate teaching strategies in science (Appleton, 1990a, 1993b) and in teacher education (Appleton, 1990b, 1994). The final version of the model could be used in a similar way, but would provide a different perspective on the learning process. New aspects of the final version of the model which would be particularly useful are the identification of the variety of information sources potentially available to students, how the teaching strategy and social context influence which of these are actually available in any one lesson, and the iterative nature of the information seeking and cognitive restructuring processes during a lesson.

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INTENTION AND PRACTICE IN SCHOOL SCIENCE EDUCATION

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ABSTRACT

This paper reports on a study of the mismatch between science teachers' stated purposes and their actual teaching of science in a secondary school. Factors affecting teachers' practices include their personal beliefs about teaching, learning and the purposes of science education, the school program and the school culture.

INTRODUCTION

Recommended teaching practices have been difficult to implement on a wide scale because the way in which teachers teach matches their image of science teaching and their knowledge of and about science (Gallagher, 1991). The implication that teachers do what they believe they should do; that is, implement teaching practices consistent with their beliefs is problematic as inconsistencies exist among teachers' beliefs about learning and teaching and teaching practice (Briscoe, 1991; Tobin, 1990; Aubusson & Webb, 1992; Hewson & Hewson 1989; Renner, 1982). At least four explanations for these inconsistencies, each relating to the conflicting demands teachers perceive to be placed upon them, can be identified in the literature.

- Lack of pedagogical knowledge. Teachers may recognise their teaching is not consistent with the views they espouse but may not know how to implement teaching practices consistent with these espoused beliefs (Briscoe, 1991; King, 1991).
- Conflicting educational pressures. Educational and social pressures may prevent teachers teaching as they think they should. Duschl and Wright (1989) argue teacher decision making is dominated by considerations for student development, curriculum guide objectives and pressures of accountability. "Teachers do not operate in an ideal world in which they are free to teach as they wish; ...(they) must plan to teach several topics per day, attempt to teach relatively large numbers of students each day, many of whom have relatively low motivation to learn, and confront problems with maintaining an environment which is conducive to learning. These factors represent forces of considerable magnitude which modify what teachers would actually like to do in their classrooms and which shape classroom processes" (Tobin & Fraser, 1987, p.15).
- Distinct pragmatic and espoused views. Teachers may have two sets of learning and teaching beliefs: those which they apply in the classroom and those which they espouse (Renner, 1982). A large proportion of teaching time involves a multitude of pragmatic, loosely connected, intuitive activities which do not to have any counterpart in teachers' stated beliefs (Hewson & Hewson, 1989). If these activities are indeed 'intuitive' then they may reflect a set of pragmatic views of learning and teaching distinct from those espoused.
- Socialisation by the school culture. The secondary school science culture socialises people into the profession to engender a teaching role consistent with the expectations of students, other teachers and school administrators which may be different from the teacher's personal views (Briscoe, 1991; King, 1991).

This paper attempts to explain the way in which a group of science teachers teach by analysing the explanations they give for their teaching practices.

METHOD

The research took place in a high school in the Metropolitan West Region of Sydney. All eight teachers in the science department participated; they will be called Chris, Joan, Dean, Lance, Hugh, Gail, Brian and Fred. The research was conducted in three phases: establishing the teachers' espoused and implemented beliefs regarding the purposes of science education; exploring the relationships among the teachers' beliefs about how they teach, their espoused purposes of science education and teaching practices; and identifying the factors which influence what the teachers do in their classrooms.

Data were collected during 1993. During school visits, teachers were observed as they went about their daily work both teaching and non-teaching. Observations were recorded as field notes. Four structured interviews were conducted to determine their views on the purposes of science education, their beliefs about teaching and learning and the factors which influence the way in which they teach. These were audiotaped and transcribed. As the interviews included discussions of instances from observed lessons or observations of teachers when not teaching, the specific content and questions varied across teachers. Unstructured interviews were conducted when conversations were initiated with teachers when they were not teaching. Data were analysed to identify the explanations teachers offered to explain what and how they taught.

RESULTS AND DISCUSSION

Teachers espoused many purposes for the teaching of school science (more than 20 were identified for each teacher). Four were identified as important by the teachers: the teaching of better thinking; student personal development; student social development; and the teaching of science knowledge. Observations of teachers in term 2 showed that six teachers taught using small groups in both practical work and discussions of science subject matter. Dean and Hugh tended to only use group work when students did practical work and favoured whole class discussions of science subject matter on most occasions.

Most lessons appeared to emphasise the teaching of knowledge. A minority emphasised the teaching of science process skills. In a few lessons teachers overtly attempted to improve personal and social development by discussing the way in which students were interacting with each other. There was no evidence of overt teaching of better thinking. Activities related to thinking (expression of ideas about practical work, concepts etc) group work (involving social skills), and process skills (experimenting, comprehension, reading, hypothesising, reporting, graphing etc) were being used as a means of learning knowledge. In this way the observations suggest that the teachers taught knowledge and did not directly teach students how to think, to work in groups, and carry out process skills but rather used students pre-existing abilities in these areas to learn knowledge. The apparent mismatch between teachers' espoused views of the purposes of science education and their teaching practice can be explained by their personal views of teaching and learning interacting with the school program and culture.

Views on teaching and learning knowledge

Teachers speak more about how to teach than how students learn, with views of learning being interwoven with descriptions of their personal teaching theories. Chris and Joan make explicit their views of learning in conversations and interviews speaking of students "constructing personal understandings" and "building their own framework". With the exception of Dean all teachers speak about learning in terms which are broadly consistent with a view in which students learn knowledge by developing understandings for themselves. Chris and

Joan refer to their view as "constructivism". Fred terms it "self learning". Lance frequently explains "they have to work it out for themselves".

Joan, Chris, Lance, Gail and Fred emphasise the need to provide the students with opportunities to develop their own explanations for scientific phenomena involving everyday materials by building on their own ideas, sharing explanations with others and testing ideas in small groups. The teachers' role is not to transmit understanding but to make it easier for the students to generate their own understandings. This involves encouraging them to conduct their own experiments to test their ideas and providing activities, using materials with which the students are familiar, to make it easier for students to make connections between learning which occurs in science lessons and pre-existing knowledge about familiar objects.

J: ...I know when I talk to them, if I relate it back to the eggmobile you can see in their eyes "Oh yes" rather than when you talk about collision trolleys. They did a prac with collision trolleys with my student teacher and they've got. - half their problems are working out what a collision trolley actually is. (Joan used 'eggmobiles' made by students to carry 'egg-passengers' when teaching a similar lesson) It's unfamiliar - so there is more than one thing to learn there. But they are - it was making sense to them more than it had done up to that point.

P(researcher): What makes it make more sense do you think?

J: I think it's the way some of them learn - relating it to what they already know - back to the constructivist stuff I guess. They can transfer knowledge from one area of real life and see that it works.

Hugh's views of learning and teaching of knowledge are different from those of the other teachers. He emphasises the need for students to gain access to the existing body of information available in science as well as use their existing knowledge to develop correct scientific understandings, mainly through teacher questioning and discussion. Personal knowledge grows from existing scientific knowledge as students learn by verifying and building on the existing logical structure of scientific knowledge, some of which they may already tacitly possess. Hugh: "I'm opposing re-inventing the wheel... I think that there are a lot of wheels that we can accept as having been invented, read about them, learn about them and understand them and move on from there." He does not teach by telling but prefers a teacher-lead discussion. The teacher, in possession of scientific knowledge, need not deliver this knowledge to the student but rather uses students' existing understanding to reconstruct the teacher's scientific view through a Socratic dialogue. "I think [teacher-moderated] discussion is an important way of learning... as you have seen in my class I do ask them questions and I draw the information out from them because I know that a lot of the information we are trying to get across they already know anyway."

Dean's view of learning is consistent with a transmission view of the teaching-learning system. He believes there are different ways of learning and different ways of teaching but emphasises teaching by giving students information according to his logical structure of the discipline: "There should be structure to what you are doing so that you can get from point A to point B...There should be a structured, and planned way to build a pattern for the kids. I believe that they should be given some information and then be told to build on it."

Views on learning to think and teaching thinking

All teachers see thinking as something which is learnt incidentally in that it is not directly discussed and analysed. Thinking is viewed as an operation learnt and developed by students when they engage in it rather than as a subject students discuss or about which students should be told. It is learnt "like you train anything else you have to participate in it and do it, and redo it" (Hugh). Thinking is learned and taught tacitly as part of a gradual process promoted by general approaches to teaching which stimulate students to think in a classroom atmosphere tolerant of diverse views. 'Science' contributes to this by providing a source of open ended investigations and problems which stimulate thinking and a scientific method as a model of problem solving to invigorate the students thinking process. Exactly how this improves thinking is not clear.

J: Science allows you to do that (develop better thinking) more because the scientific method - hypothesis, aim, method - that's one.

P: What do you mean by the aim, hypothesis -

J: The scientific method? Why does something work? Come up with an idea and then test it with an experiment and a control and then work out was the aim relevant? Yes or no. Was the hypothesis relevant? Yes or No. If no, do we need to modify it? If yes, was it the best?

P: So how does that help them to think better?

J: Well, copying someone else's ideas doesn't teach anyone to think. It just has them be a parrot. But, if it's more open-ended, if I leave it as an open thing and let them test their own hypothesis, let them develop their own aims, methods... Then later I can point out do you realise what you did. I don't always do that either, they sometimes say "Miss, I just worked out something..."

Views of teaching and learning skills

Teachers believe skills are taught by providing students with opportunities to practise their skills. Teachers explain that they should respond to students' needs as they arise helping students when they have difficulties with specific skills either individually in small groups or occasionally teaching the whole class. When teachers decide there is a need to teach a skill most favour teaching by demonstrating and telling students what to do. Teachers may also teach skills by discussing alternative approaches adopted by different students. When learning skills such as how to use equipment, Joan and Chris prefer students to learn by playing with equipment to work out how to use it for themselves.

C: It depends on the skills, sometimes through almost play, where I say I want you to work this out. With the triple beam balance for example, I often will just let them play with it for a while... So it is sort of a problem solving approach... But if there is an element of danger or if it is expensive equipment, sometimes you can demonstrate or in the case of something like reading a measuring cylinder, you can just tell and explain it. Often with them doing it with you... Because it is just simply a rule — you read from the bottom of the meniscus and as long as they realise what a meniscus is, then we're right. So sometimes it's straight telling them the rule or the way of doing it; often it's demonstrating with them following along, and then sometimes if it's applicable, I much prefer to let them discover or play to work out how to do it.

Students are usually assumed not to be learning skills for the first time in science but learning to generalise their skills to science contexts. Teachers help students when they appear to be having difficulty or correct students when they make mistakes. I get them to have a go at it (graphs) first. See what they're up to because some kids already know and it seems pointless to teach them things they already know and then if they are having problems then - if there is enough- I'll do it to the whole class, but if it is just a group then I'll work with the group (J).

Views of learning and teaching for personal and social development

Teachers promote personal development by showing a personal interest and getting to know about the students' life, family and interests outside school science. Chris: "Personal development in a sense is becoming the best person they can. That relies on relationships in the classroom and with the teacher and I try to work really hard in that. I try to make personal contact with all the kids. I try really hard to get to know someone personally. Whether it be that they've got a new baby brother or sister, or that they like sailing or that their Dad's a mechanic and their Mum is an electrical engineer or whatever it is so that every so often I can speak to them about that so that they feel good as a person with that feeling of comfort in the room which will then allow them to explore both the science and themself so that they start to feel comfortable. It's just creating an atmosphere I guess so that they trust and know me and that they begin to treat each other in the same way."

Social development is promoted by creating situations where students are working with each other, usually in small groups. "I suppose just what I've said comes into this as well. The group activity, the fact that they have to communicate with each other and work together and I suppose also realising their limitations within their own group sort of puts them in a social set up. It's largely done by group work" (Lance). Or, by telling students what is socially acceptable behaviour when their behaviour is socially unacceptable: "I'll take them aside and talk to them about it [social behaviour], and explain why I think it's inappropriate or in some circumstances it's not only just me — there is legislation against racism and sexism and I have to point that out to them and that it is not acceptable" (Chris).

Personal and social development are not taught directly but learned by accident or incidentally. It is what Joan refers to as "sub text. I don't think I actually teach it but I'm aware of it and by my attitude, by my answers, the way I don't let them put each other down in class. I think I try to create the atmosphere which focuses on the positive things and tolerance and acceptance that we all have to learn in stages of development skills".

Theory and practice: horses for courses

The teachers' personal theories of teaching and learning knowledge are different from their personal theories related to thinking, social and personal development and science process skills. Knowledge is taught by teacher-lead and group discussion, activities to provide first hand experiences, the expression of students' ideas and students' thinking things out for themselves. By contrast, thinking, process skills, social and personal development are taught by doing. For example you learn to think by thinking, to interact socially by interacting socially (working in groups) and science process skills by using these skills. The teaching of these requires the teacher to provide opportunities for students to think, work together and implement science process skills. The lessons reviewed from this perspective reveal a pattern of teaching more consistent with teachers' espoused purposes of science education such that knowledge is something about which students can think, which science processes can be used to seek and on which groups can work. The apparent observed emphasis on the teaching knowledge may be explained in terms of these teachers' different views of how to teach for different purposes rather than in terms of discrepant views of the purposes of science teaching; those they espouse and those they practice. Science subject matter knowledge is the subject of discussion in most lessons because it is the "vehicle for other learning" (Joan).

A researcher may observe a lesson involving practical work and identify a main purpose as learning knowledge about particles and specifically that there are empty spaces between particles. By contrast, the teacher may emphasise the development of thinking or tolerance and respect for differences among people as key purposes of the lesson.

C: You know the simple prac where they have 50mLs of metho and 50mLs of water - I left it up to them to work out different things they could do to solve that and they each came up with different ideas. One group wanted to put Glad Wrap over the top to make sure it wasn't evaporating, other groups said it may not weigh the same - can we weigh it - and they all went away and did their things and I was completely happy to let them do that... If their minds are working in different ways and they often are - you can't set it down as this neat little flow chart where you have to go from A to B to C - some kids will go from A to C and come back to B later on. I really like them to realise that because it makes you much more tolerant of other people. That's something that I've probably only learnt recently but I wish someone had taught me that.

Teacher personal experience

Teachers' personal experiences influence their views of the purposes of science education as well as their views of how to teach and how children learn. Gail's rejection of a transmission view of learning/teaching has been influenced by her experiences as a school science student: "I was a student from the feed-them-information sort of way of fifteen years ago... I always felt like I was at sea and I hated that." She wants her students to learn to think logically but this is tempered by school experiences in which her creativity was inhibited. This may help to explain the dabbling with independent learning observed in her year 9 science class.

G: I'm trying to get them to think logically but I'm also trying to get them also not to dampen or hinder their creativity and their imagination... I think somewhere along the line someone inhibited my creativity and my imaginative thinking and it never came back. (P: Where did that happen?) At school...Oh it was probably one of those very well organised, ordered lessons that were given...I often think that somewhere along the line at school, any creativity I had was stamped on really quickly.

Teachers make decisions about what science content to teach by considering their interests and the science information which they think they have used or needed in their lives. Science content which traditionally has been regarded as important may be deemed unimportant because it is seen to be of little use in the daily life of teachers.

C: Purely because I find them (atomic structure, laws of motion) unimportant to me - and other people, and kids. They're the classic things that when they're studying they'll say well, "why should I know this?" and it's very hard to come up with a valid reason of why they should know that. (P: What about atomic structure?) I don't know that one is ever important until you have to do something with it. As it is, it's only a theory anyway and I can't quite think in my life where it has ever saved me from anything.

Past teaching experiences may affect views of what students should learn in school science and how science should be taught. New practices may be affirmed by other teachers and through professional reading but informal observations of the teaching innovation in action in their own classes is crucial.

J: We work in isolation enough. Group work...when you see group work and the way we sit...I found when I first starting teaching I didn't teach like I teach now... I really started using it (group work) when I had a GA (General Activities) class... and I thought maybe I should be looking to encourage that sort of thing more in my classroom. And I started that without knowing other people were doing that sort of thing as well. And now I watch kids in group work and they get that chance to test their ideas on each other, they get to really have their little say because I don't have time to get around to all of them. This way they don't have to sit like little statues in the classroom and just listen. They get to be interactive and take part.

Teachers' perceptions of how and what they like to learn and think may be generalised to their students. Sometimes, the teacher may consider how they would learn best if they were in the place of the student learning science in their class. Chris: "It suits me and my personality. It's just the way I feel. That way is the way I best respond... The way I prefer to be dealt with is for someone to acknowledge my intelligence and that I can understand the situation and to present me with that and I'll often say you are absolutely right it was inappropriate. I think kids are often underestimated in their ability to understand situations like that."

Teachers' personal experiences as school students provide a set of principles and practices to be avoided rather than implemented: ideas about what not to do. By contrast, teachers' informal learning experiences outside the school environment provide learning and teaching principles to be applied in the classroom. The major role played by teachers' personal experience in shaping and providing evidence for teachers' views about teaching and learning leads to idiosyncratic teaching practices which are sensible and resistant to change.

The program

The school science program describes the science learning required in each topic as behavioural objectives (as recommended by the Junior Secondary Science Syllabus Support Document). It provides suggested activities to be found in work sheets or texts. The program attempts to implement the process approach emphasised in the syllabus but is based implicitly on the program authors' personal views of learning, teaching and what they think is important. Asked why the program had a process skills emphasis Chris explained, "Well the syllabus says so. But it's just the way I feel - my philosophy on education is that people have got to learn to do things as opposed to remember facts." In addition to a process approach, the year 7 and 10 programs have additional emphases. Year 10 has an STS emphasis involving the study of applications of science in topics such as Forensic Science and Biotechnology. It originated in Brian and Chris's desire to implement an "STS approach". Year 7 is based on a sequence of learning experiences organised according to the Generative Teaching Model: focussing, challenging, application phase (after Cosgrove, 1982).

The importance of the program authors' personal views of teaching and learning was most apparent in the development of the year 7 program where the specific knowledge content is of little importance compared to their constructivist views of teaching and learning on which it is based. "We chose topics that we knew we had a lot of resources in and we could find lots of simple open-ended pracs. In all honesty, I don't know that it is important that students ever understand the particle theory - I'm not quite sure that that is important" (Chris).

The program is not only intended to define what science is taught but how it is taught. Joan explains what she hopes the program helps to achieve. "Writing the programs in such a way that you get to teach with the constructivist approach not only if the user is familiar with it already but also for someone who hasn't come across it before - so it's a guiding type of program approach. So that constructivist is starting with what the kids know, challenging their ideas, working from there - bit more open ended. That type of thing" (Joan). This has an impact on how others teach. Although Dean espouses a transmissive view of learning/ teaching, he feels compelled to implement the constructivist approaches outlined in the program: "I'm following the program. I'm committed to following the program. I wouldn't if I was teaching it my way. I would not teach it that way."

Teachers have very little time to prepare for lessons. Many of their preparation periods are taken up with marking student work. On a number of occasions when teachers were asked if lessons could be observed, just prior to them teaching them, they responded e.g. "Sure but I'm not sure what I'm doing" (Dean) or "I don't have a clue what I'm doing but come on" (Chris). This was often followed by a check of the program and by the time the teacher had walked to the classroom the lesson appeared to be prepared. Teachers may only require a few moments to recall how to teach a lesson from previous experience and employ their personal standard teaching strategy.

The program contains activities, suggested experiments, references to textbooks etc. When preparation time is short, they may simply implement program activities in the classroom. Or, when they doubt their own knowledge in the science they are teaching, the use of program activities provide a safe option. Brian, for example, relied heavily on an ASEP genetics booklet suggested in the Year 10 program because his knowledge of biology and relevant teaching activities was weak. By relying heavily on the program and it's resources, teachers can minimise lesson preparation and relieve some of the pressure. Fred: "At times it's easy to forget the big picture and there are times in the year when you are really stressed out because of what's going on and there are dozens of things happening. It's just very easy to say we're going to go and get the text books out and you're not really answering any of the things that you know you should be doing because for that particular period it is easy to do that."

The programmed time set down to teach topics indirectly influences the way teachers teach. At the beginning of a program teachers often teach in ways consistent with their personal teaching theories but as the time for completion grows near they teach in ways which they believe are ineffective but more efficient as means of covering the required work. Brian explains: "In the time period that I want to do it in. I don't think it's (teaching by telling) the most efficient method. But I think it's the most efficient in terms of time."

Teachers are aware they often teach in ways inconsistent with their views of good teaching. It usually occurs when the time available for specified learning has, or is about to expire. When Lance was teaching friction in year 8, he spent five lessons in which students designed and conducted their own experiments to investigate factors affecting friction. Students were given time to discuss their experiment designs and findings with each other. However, in the last lesson, he ignored all but two of the six ideas suggested and listed on the board by students, to draw the class towards the conclusion that only these two factors affect friction. When asked about this shift in teaching behaviour Lance explained that he simply had no more time to spend: "I had to wrap it up. I should have finished the unit on Friday."

Other influences, e.g. the perceived importance of the knowledge being learnt, interact with time constraints to press teachers to employ their "ineffective" but "efficient" teaching strategies. When teaching DNA Fred taught a series of lessons in which he used his preferred teaching strategies, small groups, discussing, making models, to teach about the structure of DNA. He then resorted to teaching by giving a lecture style lesson in which he transmitted the information on DNA structure to the students. During this lesson he ignored questions which students raised, which were not directly related to the particular content he wanted learnt in this lesson. Both by ignoring student questions and presenting a lesson in a lecture format Fred was teaching atypically. When asked about the change in teaching practice, he explained that "they had tried it that way" (small group discussion, making models etc.) but felt they had not understood and students "have to understand DNA".

School Culture

The principal describes his vision for the school as a "traditional academic school" (Brian). In keeping with this, the school has a policy which requires all departments to use formal exams. Such school policies require testing, reporting to parents and the use of marks on reports. These requirements influence faculty policy and teaching practice. The science department has a highly structured assessment policy which includes regular topic tests, practical tests, practical assessment and assignments. None of the staff, except Dean, is in favour of the testing which is carried out to implement school policy. The main function of the tests, identified by many teachers, is to provide marks, of dubious validity, for the reports.

Tests may be counter productive because they may focus student and teacher attention on what is tested at the expense of other learning. By placing an emphasis on some aspects of science learning, tests deemphasise learning which teachers may regard as more important. "Sometimes I feel restricted by what we have to teach. You can learn a whole lot of valuable things but we don't test them because it's science - and they're not testing to see if they have grown in confidence or if they can now negotiate - they don't test those sorts of social skills at all and they're just as important - probably more important for their everyday survival than being able to use a filter funnel properly" (Joan). This may occur as tests tend to emphasise learning which is quick and easy to assess. "It is much more difficult (to test high order skills) and you have to put questions to them that enable them to analyse situations that you've given to them or synthesise something or whatever the case may be. And these type of questions require much more work on the part of the examiner in marking the tests and they're not as easy to mark as a simple question as restate so and so, or list something or draw something" (Hugh).

For teachers attempting to introduce the constructivist approach in year 7, this testing of behavioural objectives, which define the program, has proved problematic. Joan: "That's been the hardest thing because the constructivist thing is saying that if the student isn't ready to learn at this stage then OK, at least they're thinking about it and that may come six months down the track, but we give the test straight away, or in between, and they might not necessarily have achieved their objective yet."

CONCLUSION

This study identified three major influences which interact to determine teachers' practices: teachers' personal views about learning, teaching and the purposes of science education; the science program (its objectives, activities, theoretical and philosophical underpinning); the school culture (its academic tradition, students, school executive, testing regime). These influences are not all compatible. In year 7, it has been difficult to reconcile program behavioural objectives, enforced by testing, with the constructivist approach which underpins the program. Teachers cannot avoid being influenced by these different aspects of the program which not only conflict with each other but also may clash with the teacher's personal views and beliefs. The result is an inevitable tension between these clashing influences. As a result, in classroom practice, teachers may lose sight of their long term goals of education related to learning and teaching as they focus on the short term goals related to classroom behaviours, assessment and occupying a class in activity for set times.

The factors influencing teachers do not change at the same rate or in the same ways. The program is intended to reflect teachers' beliefs about what is important, the purposes of science education and beliefs about teaching and learning. Often they reflect teachers' views about what was important, past views of purposes and beliefs about teaching and learning. For some teachers, such as Joan and Chris, it is difficult for program to keep pace with innovations they are committed to and wish to implement. Even when teachers may have a clear view of how they want to teach they may not know how to prepare programs to support this teaching. For others, such as Dean and Hugh who disapprove of the innovations, it is difficult for them to modify their teaching practice as the program changes. Hence, teachers are constrained by existing structures which they themselves control but which they may be unable to quickly alter. In addition, the established syllabus and school policies, over which the teachers may have limited control, constrain teachers in their attempts to change their practice. Where teachers are able to introduce constructivist or other practices, tests reinforcing the learning of behavioural objectives within set time limits may act as disincentives to the implementation of their teaching approaches which aim to help students "construct their own views" or "work things out for themselves".

Whether attempting to implement an externally generated innovation or teach what they want to teach in the way they feel they should teach it, teaching in action becomes a compromise buffeted by a variety of complex competing factors. When the intentions of the old science education paradigm is supplanted, the structures, policies and practices may remain to inhibit attempts to introduce practices consistent with the new paradigm. In this school, the war is over but the mines and barbed wire remain to be identified and gently removed. It may be that few teachers will possess the commitment, strong minded personal and professional qualities which might allow them to overcome the range of influences operating in school science; those which prevent them teaching as they think they should. A first step towards change may be the identification of procedures and policies related to past paradigms of science education, which may once have been highly valued, but now operate as obstacles to change. This may provide an opportunity to renovate school science education. By contrast, attempts to change science teaching practice in an antagonistic environment may prove impossible for all but the most committed and may occur at great personal and professional cost.

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TEACHING SCIENCE IN PRIMARY SCHOOLS: WHAT KNOWLEDGE DO TEACHERS NEED?

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ABSTRACT

Several reviews on science education have lamented the lack of content knowledge of primary teachers and implied that improvements in this area would lead to better teaching and learning. Subject knowledge, however is a complex issue. What knowledge is required and how much? There is knowledge of the 'content' and the 'processes' of science. An elusive but essential third component has been described as syntactic (Grossman, Wilson & Shulman, 1989), experiential (Burnard, 1986) or personal knowledge. This paper argues that it is unrealistic to consider the implementation of pre-service primary science courses that will provide potential teachers with all the 'knowledge' that they will require to be an effective teacher of science. Science educators, can however, provide effective frameworks from which pre-service students can identify and develop their existing knowledge. If teachers of science have their knowledge of science set within a personal view of science the potential exists for their school science programs to be more comprehensive, dynamic, relevant and contemporary. One perspective that could provide this framework is that offered by 'Science, Technology and Society' (S-T-S).

INTRODUCTION

> "The future of science education does not lie primarily in curriculum or in technology but with teachers of science" (Baird, 1988).

Recent reforms in the science curriculum in New Zealand have placed the spotlight on teachers of science. Recognition of the critical position of teachers in the successful implementation of curriculum has once more demanded some analysis of the traditionally low profile of science within the primary sector. A personal unease with science and a lack of confidence in their roles as teachers in this discipline are among commonly cited reasons for the perceived reluctance to implement science programs (Appleton, 1992; Jeans & Farnsworth, 1992). This lack of personal interest may hardly be surprising as about 75% of primary teachers are women. Many of these women bring to science teaching their own school experience of science that was often personally irrelevant, intimidating and alienating (Kelly, 1985; Whyte, 1986; Kahle, Daniels & Harding, 1987; Kahle, 1988; Bell, 1988). The feelings of inadequacy and lack of interest have also been related to a perceived lack of content knowledge. A number of reviews of primary science education have implied that improvements in this area of content knowledge would lead to better teaching and hence better learning in science (Ministerial Task Group, 1992; DEET, 1989).

There is some doubt, however, that increasing the science content of pre-service courses would in fact lead to greater confidence in the teaching of science (Skamp, 1991; Appleton, 1992). More importantly, what actually constitutes the 'science content' required by teachers of science is rather more complex than that implied by a 'background in science'. One aspect of this required background is some knowledge of the subject itself and Shulman (1986, 1987) identifies subject matter as 'the missing paradigm' in current studies of teaching. His view of subject matter, however, is much broader than that implied by a knowledge of the subject area. He suggests that the content knowledge that underlies the teacher understanding needed to promote learning among students includes curriculum knowledge, subject matter content knowledge and pedagogical content knowledge (Shulman, 1986).

Science educators in New Zealand over the past decade have not neglected the issue of content knowledge in the teaching and learning of science within the primary sector but the focus of attention has largely been on one aspect; that of pedagogical content knowledge. This includes "an understanding of what makes the learning of specific topics easy or difficult and the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning" (Shulman, 1986, p. 9). Research projects such as the Learning in Science Project at the University of Waikato have helped to increase the understandings in this area and so enabled science educators to plan and implement school science programs that take account of, and build on students' existing ideas and interest. In these studies the 'students' have been potential teachers of primary science, teachers and children. Courses based on these ideas of constructivism and interactive teaching have had some success in increasing the confidence of teachers through pre-service and in-service science courses (Appleton, 1992). This judgement is supported by the personal observation of the writer. There is some evidence that such approaches also enable pre-service students to increase their familiarity with scientists' understandings of natural phenomena (Symington & Hayes, 1989).

While an understanding of how people learn science is critical to the implementation of effective science programs it is only one component of the understanding required by a teacher. As a single element it can, in fact, lead to rather a fragmented and limited science program. One study of final year pre-service students found that they had reduced an interactive teaching approach to a strategy for finding out children's ideas (Waghorn, 1993). While the students expressed a strong belief in this preliminary phase they did not mention carrying out the equally important phases of the model which involve challenging and developing children's ideas. Waghorn notes:

> In the minds of the student teachers the next stage in the interactive teaching model was left entirely up to the child because teacher subject knowledge was seen as not having a place in this inquiry. The rationale which the students gave for this position was that the research on which the interactive teaching model is based (Learning in Science Project) shows that teacher (imposed) knowledge is the sort that doesn't stick in the long term. The student teachers often referred to themselves as facilitators, and expressed discomfort with the view of a teacher up the front imparting knowledge (p. 82).

A study by Aubusson and Webb (1992) of primary teachers' beliefs about learning and teaching also identified a lack of clarity about the role of the teacher in the learning process:

> It seems that the participants have a clear view of how children learn and their role as an organiser of the learning environment but rarely did they explain how they would promote thinking, reflection and the modification of ideas, cooperative learning, investigating and designing and making. Yet, these were all identified as being ways in which children learn. It is as if the teacher had no role at all when the children are learning. ... they define their role by defining the children's role (p. 25).

The stance required by the teacher in this learning process, however, is both active and critical. Osborne and Freyberg (1985) describe the success of the application phase of their model for teaching and learning as "dependent on active, intelligent teaching" (p. 117).

Shulman (1987) sets this description of the interactive teacher within a context of subject understanding: "Indeed, we have reason to believe that teacher comprehension is more critical for the inquiry-orientated classroom than for its more didactic alternative" (p. 7). As a science educator and teacher of science to primary pre-service students I am seeking ways to promote such a role for the teacher of science. In this role teachers would bring a dynamic knowledge of learners within concurrent understandings of the curriculum, of the subject and of the pedagogical content knowledge. While the successful blending of all these components are essential elements in the teaching process, this paper focuses on the critical areas of subject matter content knowledge and its associated pedagogical content knowledge. In particular, an attempt is made to analyse the essential elements of these component parts and to suggest one conceptual framework that may assist in developing on-going understandings so that teachers of science continue to increase their personal knowledge in science and of teaching and learning in this subject area.

SUBJECT MATTER CONTENT KNOWLEDGE

Subject knowledge can be described as content, process and 'personal' knowledge. 'Content' knowledge of science or propositional knowledge is the 'knowing' of facts, theories and ideas, and some understanding of the organising principles and central contexts of the discipline. In a study of native plants, for example, this may involve a knowledge of the scientific names of a variety of plants, their preferred environment and something of their form and function.

Secondly there is knowledge about the 'process' or skills of the discipline. This has been termed the practical knowledge, the knowing 'how' (Burnard, 1986). Again using the context of plants, such knowledge may involve classifying plants on the basis of leaf and flower structure, in making measurements of growth over a period of time or recording detailed descriptions of a variety of plants in the field.

Through the 1970s and 1980s the approach to primary teaching of science was largely process orientated (Kruger, Summers & Palacio, 1990; Russell, Bell, McGuidan, Qualter, Quinn & Schilling, 1992). There was a focus on such skills as observation, hypothesising, recording, interpretation and application. The idea of developing 'content' knowledge was masked by the emphasis on the development of skills and attitudes and by a rather simplistic interpretation of the role of the teacher when operating from a constructivist perspective. Interactive teaching models that were proposed to take account of students existing ideas (Biddulph & Osborne, 1984) led some to believe that the teacher only needed to be a 'fellow traveller' in the learning. There is currently a move to give greater emphasis to the teaching of conceptual understanding in science (Linn, 1992). As well as developing process skills and attitudes children are expected to develop knowledge and understanding of, and about science (Kruger et al., 1990). There is also a demand to ensure that the content and skills of science are set within relevant contexts (Fensham, 1985). These initiatives put additional demands on the teacher of science and highlight the limitations of a teacher who has only a knowledge of the 'facts' and ideas of science and of the processes involved. Teachers of science need not only knowledge of the content and process of science, but also a view of the dynamic nature of science itself. The New Zealand science curriculum (Ministry of Education, 1993) states that through "using systematic and creative processes of investigation, scientists produce a constantly evolving body of knowledge" (p. 7). It argues that "students should appreciate that social and cultural frameworks influence the way scientists work and that understanding in science changes (p. 24). It also maintains that learning in science is enhanced when learning environments reflect contemporary science (p. 10). For teachers to generate such a vision with their students and to be continually developing their own understanding of science, they need to have some personal notion of the scope and parameters of science itself.

The opportunity to establish a personal perspective perhaps lies within the third component of subject knowledge. There is a diversity of views about this area of subject knowledge and it appears within the literature under a variety of names. Bereiter (1992) argues that a depth of conceptual understanding is achieved when the facts and skills of science are embedded within explanatory frameworks. He maintains that isolated facts can not constitute cultural literacy unless they contribute to an understanding of social and cultural events. Grossman et al. (1989) refer to this as syntactic knowledge. The syntactic knowledge of one teacher will lead to a definition of science as a set of specific techniques and lead another person to define it as the inquiry of the world around us. Burnard (1986) calls this personalised form of subject knowledge, "experiential knowledge", and argues that it is encouraged through reflection in action. He maintains that it is the subjective and affective nature of any encounter that contributes to this sort of knowledge and that it reflects the unique human perception of an experience.

Whatever term is employed, it is this type of knowledge that provides the basis for the development of more personal engagement with the subject, and that helps to develop an understanding of the nature of knowledge within the discipline. For science, it is the 'content' and 'skills' of science immersed within a view of, and about science. It is this personal vision that enables a learner to ask new questions and to set their own goals for further investigation. In the context of the study of native plants the nature of the exploration would be dependant on the individual learner. For one, it may lead to a knowledge of the medicinal properties of the plants, for another the growing and tending of a particular plant.

PEDAGOGICAL SUBJECT KNOWLEDGE.

For teachers there is an additional component to the third dimension of subject knowledge. Teachers need not only a complex knowledge base to implement an effective program but they also require the ability to transform knowledge into pedagogical content knowledge (Peterson & Treagust, 1992). Tamir (1991) maintains that such transfer is only useful when it becomes personal practical knowledge. Tamir argues that the problem a novice teacher faces is to absorb and internalise knowledge of the subject and of teaching in such a way that it becomes his or her personal practical knowledge which can be subsequently applied in teaching. Shulman (1986) suggests that the ability to transform subject knowledge into pedagogical subject matter knowledge is assisted by reflected practice.

There are numerous explanations of what constitutes the required subject knowledge in relation to pedagogical knowledge. McDiarmid, Ball and Anderson (1989) argue that a teacher's capacity to pose questions, select tasks, evaluate pupils understanding and make curriculum choices all depends on how they understand the subject matter. They suggest that teachers must develop a flexible, thoughtful and conceptual understanding of their subject matter if they are to create or choose representations that enable pupils with diverse knowledge, experiences, expectations and values to develop similar understandings. Rovegno (1992) refers to teachers with strong content knowledge as helping pupils to go beneath surface-level knowledge of facts and formulae to understanding the deeper meanings of concepts and the processes of coming to know a discipline. Without a deep, integrated understanding of content, the potential for teachers to help children learn 'worthwhile' content is diminished. Rovegno suggests that "knowing elementary content means knowing the meaning of that content and its pedagogy in relation to the soul and substance of the larger discipline" (p. 262)

DEVELOPING 'MEANINGFUL' FRAMEWORKS FOR KNOWLEDGE IN SCIENCE

As a science educator I am interested in providing opportunities for my students to develop such a depth of understanding. Our existing compulsory science education courses enable students to develop knowledge of how to teach science and help to increase their understanding of some scientific concepts. The focus within the courses on alternative conceptions, conceptual change and interactive teaching strategies have served to place attention primarily on the learner of science. This emphasis on its own, however, is somewhat limited in vision as it does not necessarily demand that a teacher asks, "What science?" and "Whose science?" It may be possible, though, to create an environment where student teachers do identify and develop their personal view of science and then use this perspective to continually question and seek answers for themselves. Such a position casts the potential teacher of science into the role of a continuing learner but in a more personal and pro-active sense than merely a fellow traveller in learning alongside their own students.

The learning of concepts and knowledge, however, can be threatening and off-putting so adult learning of conceptual science needs to be within "motivating contexts" (Kruger et al., 1990). Barnes (1989) suggests that teacher education needs to build programs that develop meaningful frameworks for thinking about teaching. Fensham (personal commmunication) used the term 'constructivist technician' to describe teachers who know about constructivist views on learning and about activities that help to engage students in thinking but who are unable to set this within a personal, dynamic and changing conceptual framework. O'Loughlin (1992) identifies an emancipatory constructivist as a reflexive, critical practitioner who is open, exploring and who has some understanding of the socially constructed nature of reality. O'Loughlin asks "can we construct a pedagogical environment in which a teacher can experience the power of constructing critical knowledge for themselves?" (p. 338).

There are a number of 'frameworks' that may be useful for developing dynamic, personal knowledge of, and about, science. The area of science that I am interested in exploring as a useful framework is that offered by a Science-Technology-Society (S-T-S) perspective.

SCIENCE, TECHNOLOGY AND SOCIETY (S-T-S)

The science, technology and society link was coined in the late nineteen seventies largely with the aim of setting science within an everyday social context. It was advocated that scientific ideas and processes should be linked both to applications in associated technology and implication in relation to the influence of, and impact on, people. While the American movement approached the study of science, its applications and social context largely through environmental issues the British counterpart had a concern for the philosophy and sociology of science (Solomon, 1988). It was thought important that the nature of science should be studied and that open discussion of the social effects of science-based issues should be an objective of education (Solomon, 1988).

Two important arguments were developed to support this approach to the teaching and learning of science. Firstly it was argued that this emphasis on the social and ethical would motivate reluctant learners of science, especially girls. Many girls (and women) feel quite negative towards science and see little relevance in it to their everyday lives (Whyte, 1986; Bell, 1988). They view science as being devoid of people and as a process where qualities of being logical, rational and objective are emphasised at the expense of being creative or intuitive. Girls often find it difficult to identify with such a process and their feelings of exclusion are reinforced by the male orientated contexts and applications commonly used in science (Bell, 1988). To engage the interest of girls the contexts of science need to be embedded in real-world social concerns and in people orientated contexts.

The second argument for an S-T-S approach to a science program is that it promotes learning (Solomon, 1992). The setting of science within relevant contexts encourages more students to be involved, to ask questions, to make links with prior knowledge and hence to achieve a deeper understanding. The application of their knowledge in contexts that seem relevant to the learner also provides scope for the development of higher order thinking skills where information is gathered and applied in the process of finding solutions (Zoller, Donn, & Wild, 1991). Skills in problem solving and decision making are viewed as essential components of scientific literacy.

The S-T-S movement has largely been visible within upper secondary science courses but it has the potential to provide the manageable and coherent framework to guide teachers in the development of their knowledge of science and the teaching and learning of science. The learning of isolated scientific ideas and concepts is likely to reinforce the notion of science as something that occurs in classrooms and that is somewhat removed from everyday life. A S-T-S perspective on science could facilitate the transfer of these scientific ideas into a useful personal schema of understanding by building on teachers' interest in people, ideas and social issues which are all foci of primary teaching. In this way the content and process knowledge of science would be set within a framework of 'experiential' or personalised knowledge.

For primary teachers, the majority of whom are women, learning about the content and process of science within a view of science, such as that provided by a S-T-S perspective, would identify science as more accessible, engaging and relevant to them and their existing knowledge. It provides a framework for the exploration of the interactive links between science and its diverse applications in everyday contexts, between science and people 'doing' science and the complex relationship between science and social issues. All these aspects being critical components in including the interests of many girls and women in science.

This interest in everyday contexts and current issues is reflected in common primary science topics such as recycling, endangered plants and animals, energy conservation, whaling, health and disease and conservation. If school science programs are to be relevant and contemporary they need to mirror developments within these areas. Over the past few years, for example, there has been a change of focus in waste management from one on recycling to an emphasis on 'reduce-reuse-recycle'. A S-T-S approach could be a useful framework for the development of a scientific perspective on such issues and assist teachers to develop their understanding of science as a dynamic and changing body of knowledge.

The teaching of these potentially S-T-S topics rely on some scientific as well as technological knowledge. Many surveys have shown that people have a limited knowledge and ambivalent attitudes to science and technology (Ministerial Task Group, 1992) but Hardy (1992) suggests that much of this research is based on simplified assumptions about the nature of science and technology and has not considered how people obtain science and technological knowledge and use it in every day life. Initial findings of Hardy's RETEL project suggest that everyday technological and scientific knowledge is constructed by individuals in dynamic contexts, economic and social elements being critical factors. There is in fact, a complex interaction between everyday knowledge of science and technology, contexts and individual behaviours. Hardy uses this evidence to argue for education in science and technology that :

- emphasises the changing social, economic, political contexts in which they occur;
- relates science and technology to the everyday lives of students in a critical and reflective manner;

- recognises that the feelings, values and constraints of a context will always affect the student's and adult's construction of knowledge and that this is not necessarily irrational;
- is concerned with developing self esteem for all students in science and technology (p. 186).

While frequently we use these descriptors to identify the science for school students, teachers too are learners and so they too need the opportunity to develop their scientific literacy within this applied vision of science and science education. It is the exploration of science in these settings that will help teachers of science in primary schools to confront their own unease with the subject and to develop greater confidence in their ability to be effective facilitators of their own students' learning.

A S-T-S perspective has another dimension that could make it a constructive force in the current curriculum developments. It is an effective vehicle for teachers to reflect on the historical contexts that have led to the contemporary views of science, both in society and in schools and their personal position in relation to these factors. Goodson (1991) maintains that a similar approach is required in the study of curriculum. In curriculum too there is a need to develop a cumulative understanding of the historical contexts in which the contemporary curriculum is embedded (Goodson, 1991). He argues that what is required is an understanding of the social construction of curricula at the levels of prescription and process and practice. Too often, according to Goodson, the focus is on the present rather than on the constraints beyond the event, the school, the classroom and the participant. What is needed, is something that stays with the participants, in this case, the teachers, so that they develop useful 'cognitive maps' that aid understanding and help locate the parameters to their practice. Within the context of science this would enable teachers to see the social construction of their own ideas about science and so help to free them of their perceived constraints such as a lack of knowledge and confidence. It could also help teachers to identify their everyday knowledge of science and scientific ideas that could be utilised in the planning and delivery of an interactive science program.

There is a compelling argument for integrating a S-T-S perspective of science into the education of potential teachers of primary science. It would serve to do more, however, than provide a personal conceptual framework for developing knowledge and skills in science. It would also provide an effective strategy for linking the structural and prescriptive framework of the science curriculum to its philosophy of teaching and learning. It is in fact a perspective that is advocated in this document, although in a manner that is implicit rather than obvious. An S-T-S curriculum is human and society focused, problem centred, and responsive to local issues (Roth, 1989). These aspects are evident in the stated aims of science education (Ministry of Education, 1993, p. 9) and in the 'Science for All' statement of the science document. Science in the New Zealand Curriculum argues that:

> Science and technology are major influences in many aspects of out daily lives; at work, at play, and at home. Our dependence on science and technology demands a high level of scientific literacy for all New Zealander's and requires a comprehensive science education for all students, as well as for those who well have careers in science and technology (p. 7).

An S-T-S emphasis is again evident in the learning strands where it is argued that as students' ideas evolve they should be acquiring an understanding of the nature of science and its relationship to technology. Consequently, it is advocated that when planning and implementing a science program the strand, 'Making Sense of the Nature of Science and its Relationship with Technology' should be integrated into the four contextual strands. This would result in programs that had a strong S-T-S emphasis as the three achievement aims for this strand are that students will use their developing scientific knowledge, skills and attitudes to:

- critically evaluate ideas and processes related to science and become aware that scientific understanding is developed by people, whose ideas change over time;
- explore the relationships between science and technology by investigating the application of science and technology and the impact of technology, on science;
- become familiar with personal, community, and global effects of the application of science and technology (p. 24).

CONCLUSION

The subject matter content knowledge of a teacher is a critical component in teaching. It affects what teachers teach and how they teach it (Carre & Bennett, 1993). Shulman (1987) included subject matter content knowledge as one of the essential 'knowledge bases' needed to enhance understanding amongst students. He also emphasised the importance of a 'knowledge base' of curriculum knowledge, pedagogical content knowledge and a knowledge of learners (1987, p. 8). A number of research projects have helped to inform teachers of science about the understandings and misconceptions of many learners of science and have identified a range of strategies that have assisted teachers in translating the subject into classroom programs that take account of the existing ideas and interests of the students. Research that has focused on the content knowledge of primary teachers' has investigated their understanding of key concepts in science and has highlighted either their lack of knowledge of many scientific concepts or a misunderstanding of these key ideas (Summers & Kruger, 1994). These findings led Summers and Kruger to ask "to what extent can ordinary, generalist primary school teachers develop a non-trivial and lasting understanding of science concepts?" (1994, p. 500).

I have argued in this paper that an S-T-S perspective on science has the potential to provide teachers of primary science with the 'motivating contexts' and 'meaningful frameworks' for use in their development of a deeper and 'lasting' understanding of science. In particular, it can provide a way of linking the ideas and processes of science within a structure that is personally engaging and relevant. That is the setting of propositional and practical knowledge of science within 'syntactic', 'experiential' or personal knowledge. S-T-S is also a framework that may be useful in aiding teachers integrate the knowledge components that Shulman (1987, p. 8) argued that are required to teach. It enables investigations in and about science, is a perspective that is advocated in the New Zealand science curriculum and provides a context for relevant, contemporary science programs. Further, it provides a cohesive framework for linking personal knowledge within an active teaching situation.

It is perhaps an irony that the generalist primary teacher of science is more likely to be receptive to implementing a science program with this focus than a 'specialist' teacher of science. In their study of teachers involved in the teaching of a S-T-S program Duffee and Aikenhead (1992) found that a person who most easily adopts a S-T-S type course is not the teacher who has a narrow orientation toward pure science. S-T-S could well be the avenue for both teacher and curriculum development that could actually achieve some significant changes to the teaching and learning of science in the primary school. This may, in time, help to challenge the traditional vision of science so prevalent in secondary science and that continues to limit the scientific literacy of students, and consequently primary teachers.

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PRE-SERVICE TEACHERS' USE OF PROBLEM-SOLVING IN PRIMARY SCIENCE

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ABSTRACT

The use of problem-solving in science instruction implies a change in the teacher's role from dispensing content information to encouraging critical reflective thinking in the student. For problem-solving to become an integral part of the science curriculum, teachers must make it the focus of their instruction. This study investigated the extent to which pre-service primary teachers used the problem-solving approach in their science instruction. It also identified the factors affecting their efforts to teach science using this approach. The issues considered are important in whether problem-solving becomes part of the science curriculum, as teaching behaviour influences student learning outcomes.

INTRODUCTION

In recent years, the use of problem-solving in science instruction has received increasing attention. Rather than teach science as a body of facts, teachers are encouraged to employ teaching techniques that foster problem-solving skills. However, the use of problem-solving in teaching science implies a change in the teacher's role from dispensing content information to encouraging critical reflective thinking in the student. The consequent teaching approach would also be different. The use of an inquiry-oriented, investigative approach in teaching science has often been advocated. This suggests the use of a variety of teaching techniques that have been linked to the development of problem-solving skills in the context of science education. For example, Pérez and Torregrosa (1983) advocate that in a problem-solving approach, teaching strategies that reflect the process and nature of a scientific investigation should be adopted. The nature of the investigative task or problem should also to some extent involve a novel situation (Gagné, 1977), be open-ended in nature rather than have one correct or obvious answer (Garrett, 1987, 1989), require the use of higher-level thinking skills beyond the knowledge and comprehension levels, and emphasize the process towards attaining the solution rather than the correct solution only. Lock (1990) argues that in order to develop inquiry skills in problem-solving investigations, it is important to enhance the open-endedness of practical work by providing opportunities for students to have more control over the identification of the problem, planning, and interpretation of results. If students are given the problem, together with the detailed procedure and solution, little if any problem-solving is present.

Pizzini, Shepardson and Abell (1989) proposed a problem-solving model for science instruction based on the assumption that a problem needs to be identified and defined by the students for it to be meaningful to them, and that they meaningfully learn problem-solving skills and concepts through concrete experiences in solving problems in science. This model is less teacher-directed and less procedurally structured to encourage students to become involved in their own learning. It encourages an inquiry approach that is as open-ended as possible, with activities that stress divergent thinking, where there may be a variety of acceptable solutions to the problem, and where the resources and methods are student-centred. Students brainstorm to identify and formulate a researchable question or problem in science and generate and implement their plans for finding a solution to the problem. Detailed 'recipe-following' procedures are not given. Students design their own experiment, decide what to do, how to do it best, what data are important, how accurate measurements must be, and why each step in the process is necessary. They also form hypotheses, predict outcomes, collect and analyze data, and interpret the results. They then present their findings, solutions, and conclusions to teachers and fellow students.

Studies by Abell and Pizzini (1992) and Pizzini and Shepardson (1992) have shown that in classes where the teacher adopted the problem-solving approach (compared to a control group which did not), there was increased use of brainstorming, an increase in time allotted to identifying, refining and presenting the problem, as well as more student-selected research questions and student-designed investigations. The teachers also substantially decreased time spent on expository and procedural talk, fact stating and explaining. This shift in control of learning from the teacher to the students is essential to developing student thinking and problem-solving skills. First-hand student interaction with materials which ensures active processing of ideas is also valued in the problem-solving approach (Martens, 1992). The use of small group settings which encourages student-student interactions and co-operative group work, where students pool their efforts together, is also considered to be effective for problem-solving investigative tasks. While the change to a problem-solving approach is desirable, teachers also experience constraints (e.g. time constraints) in implementing this approach in their science classes. Pre-service teachers could well face further constraints. This study investigated the extent to which pre-service primary teachers used the problem-solving approach in their science instruction. It also sought to identify factors which hindered their efforts in teaching science using this approach.

METHOD

Sample

The sample consisted of 100 pre-service primary science teachers (77 female, 23 male) who were in the second year of their Diploma-in-Education programme (77 in the Dip-Ed and 23 in the B.A./B.Sc with Dip-Ed). Their mean age was 22.1 years (s.d.=2.0 years). Fifty-five percent had passed 'A' level science (Grade 12), 30% had attained 'O' level science (Grade 10), and 15% had studied science up to the lower secondary level. The 'A' and 'O' level examinations are national examinations. All had studied English as a first language and all their science classes had been conducted in English. In their science methods classes, they were taught and encouraged to use an inquiry investigative approach to teaching science which would foster problem-solving skills. The use of hands-on activities was also advocated. The pre-service teachers had 15 weeks of teaching experience in primary schools; 7 weeks in their first year of the Dip-Ed programme, and 8 weeks in their second year.

Instrument

A questionnaire was developed to measure the teachers' extent of use during their teaching practice of instructional techniques associated with a problem-solving approach to teaching science. Items focused on the pupils' tasks, the nature of questions or problems in science investigations, and the time spent on various activities during a typical science lesson. They were adapted from the instrument used by Lawrenz (1990) in her survey of science teaching techniques associated with higher-order thinking skills. Some items were modified and additional ones were included based on existing knowledge and theoretical considerations consistent with the literature on the problem-solving approach in science teaching. For example, items that represent an emphasis on problem-solving involve tasks that require more reflective thought such as designing an experiment, or pertain to questions that are open-ended and require higher levels of thinking. On the other hand, activities oriented to following detailed instructions and verification of taught concepts, or questions requiring the use of definitions and recall of information rate low on problem-solving.

The teachers' views about the factors affecting their use of a problem-solving approach in teaching science were also sought. Items aimed at identifying these constraints listed factors identified by Abell and Roth (1992), Martens (1992), Tobin and Fraser (1989), and Tobin and Gallagher (1987). The teachers were asked if each factor interfered with their efforts to teach science in a problem-solving manner, and how it affected them. The questionnaire was administered during a regular lecture period after the teachers had just completed their second year teaching practice.

RESULTS

Extent of use of problem-solving approach

Nature of students' tasks. Table 1 shows the teachers' responses to the nature of students' tasks. Both percentages and mean score for each item are given. As shown in the table, when engaged in activities or experiments, students often carried out specific activities from the workbook or teachers' worksheet, worked in small co-operative groups, followed detailed instructions to perform the activity or experiment, and interpreted the results of their

TABLE 1
PRE-SERVICE TEACHERS' RESPONSES TO NATURE OF STUDENTS' TASKS

	Item	Mean	*S.D.*
1.	Carry out specific activities from the workbook or teacher's worksheet.	4.50	0.66
2.	Work in small, co-operative groups.	4.32	0.68
3.	Follow detailed instructions to perform the activity or experiment	4.16	0.71
4.	Interpret results of their experiments.	3.94	0.86
5.	Ask questions for procedural clarification.	3.75	1.05
6.	Form hypotheses about the outcomes before carrying out the activities.	3.23	1.14
7.	Perform experiments to verify previously taught concepts.	3.08	0.97
8.	Present their data and prepare a means to communicate their question or problem, method, results or conclusion.	2.99	1.14
9.	Perform experiments to demonstrate a phenomenon.	2.89	1.22
10.	Identify a list of appropriate apparatus and resources for their practical activities.	2.74	1.27
11.	Identify a researchable question or problem themselves.	2.71	1.02
12.	Are given the opportunity to list as many questions as possible.	2.68	1.17
13.	Design an experiment with little or no assistance.	2.26	1.13

Mean scores are based on a scale of 1 = almost never to 5 = very often.

experiments. The tasks that students engaged in least often included identifying a researchable question or problem themselves, listing as many questions as possible about a topic, and designing an experiment with little or no assistance.

Nature of questions and problem in science investigation. The percentages and mean scores of the responses to the 'Nature of Questions and Problem in Science Investigation' are shown in Table 2. As can be seen from the table, the teachers reported that often, the problem was one to which the teacher knew the answer, the solution required students to give their reasoning, and that the solution required simple recall of specific information. On the other hand, problems that had no obvious answer or known answer, that were posed by the students, that required critique or analysis of a suggested solution, or that used tabular or graphical data were least often used.

Time spent on various activities. The most common activities were completion of workbook or worksheets, followed by hands-on activities or experiments, explanation of concepts by teacher, co-operative group work, and discussion by students. Activities carried out least often included administrative routines and reading textbook. Twenty-eight percent of the pre-service teachers reported that they often or very often made use of activities beyond those found in the textbook that promote problem-solving skills, 44% indicated that they sometimes did, while another 28% said that they seldom or almost never did. Ninety-two percent felt that it was important to integrate problem-solving into daily lessons but 80% perceived that there was a lack of opportunity for problem-solving in science lessons in the present classroom structure.

Factors affecting the use of a problem-solving approach

Table 3 shows the pre-service teachers' responses to questions on factors affecting the use of a problem-solving approach. The factors which many felt hindered their use of a problem-solving approach included the pressure to first cover content tested in exams, time-tabling constraints, inadequate resources on problem-solving activities, and physical constraints of the classroom or school. Four groups of factors that affected the pre-service teachers' use of the problem-solving approach were identified. These pertain to the teacher, the students, classroom management and the school system. They are described below along with comments made by the pre-service teachers which illustrate the nature of the factors.

Factors pertaining to the teacher. Some pre-service teachers had limited formal content knowledge in science and thus had feelings of inadequacy. Others were unsure of how to use a problem-solving approach in teaching science. If teachers have limited content and pedagogical content knowledge, it would be difficult for them to set challenging problem-solving tasks that had high cognitive demands:

* "At times, my knowledge of concepts worried me as I feared wrong information might be disseminated."
* ".....interfered with my effort to try out many approaches."
* "teaching suggestions in the teacher's guide are very predictable. How to solve a problem when there are no problems?"

A need to maintain control over the students' learning activities and thinking, a preference for predetermined "correct" answers and a liking for things to be definite rather than unexpected minimized opportunities for problem-solving:

* "afraid to go out of track and waste time on information which pupils need not know for that level."
* "if not, pupils will give very different answers in their work."

TABLE 2
PRE-SERVICE TEACHERS' RESPONSES TO NATURE OF QUESTIONS AND PROBLEM IN SCIENCE INVESTIGATION

Item	Mean	*S.D.*
1. The problem is one to which the teacher knows the answer(s).	3.89	0.79
2. The solution requires pupils to give their reasoning.	3.81	0.71
3. The solution requires simple recall of specific information.	3.74	0.89
4. The solution requires knowledge of definition of concepts.	3.68	0.90
5. The solution requires the application of concepts to novel situations.	3.40	0.94
6. The problem requires more than one step to reach a solution.	3.39	0.77
7. The problem has more than one possible solution.	3.20	0.90
8. The question is a minor variation of others given in class or for homework.	3.17	0.82
9. The problem has only one correct solution.	3.02	0.88
10. Pupils decide on the method used to solve the problem.	2.80	1.02
11. The question or problem has no obvious answer(s).	2.68	0.89
12. The problem is posed by the pupils.	2.67	1.07
13. The question requires the critique or analysis of a suggested solution to a problem.	2.64	0.97
14. The answer is not always known; it may be unknown.	2.39	0.88
15. The solution to the problem requires the use of tabular or graphical data.	2.19	0.88

Mean scores are based on a scale of 1 = almost never to 5 = very often

- "it works best for pupils to learn a fixed outcome."
- "afraid I may not be able to cope with the unintended outcomes."
- "especially when pupils question."
- "those that I'm not prepared for (to answer or explain)."
- "sometimes experiments do not yield the desired outcome."

Factors unique to pre-service teachers include the co-operating teacher's expectations and supervisor's evaluative position. The presence of the teaching practice supervisor also made the pre-service teacher wary about 'taking risks' in using the problem-solving approach:

- "as my co-operating teacher doesn't believe in the problem-solving approach and having the pupils do the experiment, so most of the time if she comes into the classroom, I'll cater to whatever things she wants to see in my teaching."
- "problem-solving is a good approach, but it's time-consuming. My supervisor or co-operating teacher may fail me in time management."
- "co-operating teacher wanted me to finish everything in the textbook as soon as possible."
- "sometimes results are unpredictable and you are afraid you can't handle them and thus get a lower grade."
- "if supervisors see messy classroom, they either fail or give low grades for class management."

Factors pertaining to the students. Students' unfamiliarity with a problem-solving approach and lack of ability also deterred some teachers from using the approach. These teachers felt that their students had been conditioned to learn in the 'traditional' way in being 'spoon-fed' by their teacher and would need a long time to adapt to a new approach. The pupils' weakness in language and the lack of ability to co-operate in groups, identify a problem, design an experiment, hypothesize and interpret results were also cited as problems. The pre-service teachers were also apprehensive that the students' inability to solve problems would lead to their reduced interest in learning science and result in management problems.

TABLE 3
PRE-SERVICE TEACHERS' RESPONSES TO THE FACTORS
AFFECTING THE USE OF A PROBLEM-SOLVING APPROACH

	Factor	'Yes' Response (%)
1.	Feel pressurized to first cover content that will be tested in exams.	83.0
2.	Time-tabling constraints.	81.0
3.	Inadequate resources on problem-solving activities.	79.8
4.	Physical constraints of classroom or school.	70.0
5.	Students' lack of ability.	65.0
6.	Need to maintain control of students' learning.	62.6
7.	Problem-solving activities are too time-consuming.	60.2
8.	Lack of administrative support.	57.7
9.	Unsure of how to use a problem-solving approach in the classroom.	52.5
10.	Limited formal background in science.	52.0
11.	Feelings of inadequacy about science content knowledge.	51.5
12.	Like things to be definite.	49.0
13.	Pupil behaviour.	48.5
14.	Feel uncomfortable that unintended outcomes may occur.	41.0
15.	Classroom management.	40.0
16.	Co-operating teachers' expectations.	39.2
17.	Supervisor's evaluation.	39.2
18.	Colleagues' advice that problem-solving approach is not feasible.	37.8
19.	Students are not motivated to learn.	32.3

The less able students may also circumvent the need to think in problem-solving tasks by resorting to disruptive behaviour. A lack of motivation to learn and hence to think, on the part of these students made it difficult for a problem-solving approach to be used. Hence the pre-service teachers would tend to reduce the cognitive demands of the academic tasks assigned to enable their students to cope with them in a procedural manner.

* "students in my school are too used to spoon-feeding from the teacher."
* "pupils do not know how to work in groups and they have very little knowledge of how to present their findings and hypotheses to the class."
* "their lack of ability will cause time-wastage and this time is spent unproductively."
* "some students are so weak in English that they can't understand simple instructions."
* "can they understand instructions? Would they sit back and watch their friends do all the work?"
* "pupils' inability in solving (problems) leads to their reduced interest in learning science."

Factors pertaining to classroom management. The extent to which the teachers were able to cope with the disruptive behaviour of their class affected the efficacy of their teaching. When management problems become excessive, little basic learning is achieved, let alone that at the higher cognitive level. The teachers felt that with problem-solving activities in group work, students tend to become over-excited and rowdy, and feared that things would get out of hand:

* "most problem-solving activity, if it gets out of control, will lead to noise and unnecessary wastage of time."
* "At times, pupils may be arguing among themselves, especially boys. They may result in violence. Time is being wasted in controlling them."

Factors pertaining to the school system. Many pre-service teachers felt compelled to prepare their students for tests and examinations. The constraint of having to cover the prescribed content in a scheduled time and the concern for accountability to their principal, co-operating teacher and students' parents tended to make them emphasize rote learning and correct answers to enable their students to answer questions similar to those in the exam:

* "what parents and principals are concerned about is the grades and not the wide knowledge acquired."
* "....school office stressed that (exam results), hence your approach had to take a back seat."
* "all my co-operating teacher wants me to do is to complete the syllabus fast and drill them with piles and piles of worksheets."
* "we are pressurized to complete the content that would be tested for exams even if it means that the students should memorise the topic."
* "...co-operating teachers kept urging us to finish teaching the concepts without caring whether pupils truly comprehend the concepts."
* "we can't afford to waste time by doing such problem-solving activities."

Some teachers also tended to perceive the problem-solving approach and regular teaching as dichotomous and did not think of weaving them together; that is, teaching the topic via problem-solving:

* "problem-solving approach (can be) used after content required taught."
* "...there will not be enough time to cover content for exams...I will rather spend more time revising than doing problem-solving activities."

Problem-solving activities were perceived as time-consuming, and several pre-service teachers remarked that the three to five periods allotted to science per week were insufficient for problem-solving activities. Some were not given blocked periods and felt that with one-period lessons, it was difficult to conduct a lesson which focused on problem-solving especially if they had other classes before and after their science period and they had to set up materials and clear up after the lesson .

The teachers also reported facing constraints such as the limited space to conduct science activities comfortably, the difficulties faced in getting access to the science room and other facilities, the lack of appropriate and relevant activities and materials, and the inconvenience of having to search for such material beyond the prescribed textbook and workbook:

- "certain equipment are not available and you've got to take the trouble to 'shop around' for them."
- "lack apparatus, small science labs, no science technicians, no funds for buying necessities."
- "too much effort and time is needed to look for suitable materials."
- "if apparatus is not provided in school, teacher has to incur a great loss (in cost) in getting these materials."

The teachers who were discouraged from using this approach indicated that teachers in their school seldom used it and hardly carried out any experiments. These colleagues preferred teaching directly from the text, gave the class all the facts and believed that traditional teaching methods were more feasible. They found using a problem-solving approach too much trouble, too much of a risk, "a waste of time", and considered finishing the syllabus more of a priority:

- "many experienced teachers are not in favour of it no matter how hard I try to convince them. They claim that it is not pragmatic."
- "they feel that students should not try the activities as they are too time-consuming and messy. Teacher's demonstration is sufficient."

DISCUSSION AND CONCLUSION

Although most of the pre-service teachers believed that it was important to use a problem-solving approach in teaching science and their responses appeared to indicate a reasonable variety of instructional techniques, the results of the study support their commitment to the problem-solving approach only to a limited extent. The teachers faced a number of difficulties constraining their use of the problem-solving approach. These include personal attributes such as their limited academic and pedagogical content knowledge and their strong belief in maintaining control of students' learning activities; the ability of their students; their concern about classroom management problems; and contextual factors operating within the school system. The latter includes the expectations and beliefs of their co-operating teachers and principals, the accountability for pupils' results, time constraints, and the difficulty and inconvenience in obtaining appropriate resources.

The teachers attributed their difficulties with using the problem-solving approach mostly to factors pertaining to the school system. Their concern for accountability to their principal, co-operating teacher and students' parents made them hesitant in taking risks. They were thus oriented towards covering prescribed content in the allocated time and drilling their students in getting correct answers and satisfactory grades. Many felt pressured by the demands of the assessment system as students' test scores were perceived as tangible evidence of success and good teaching. Thus, there seems to be a discrepancy between what schools reward and the type of long-term but less tangible intellectual development facilitated by reflective problem-solving. The teachers' decision to use a problem-solving oriented or direct instruction approach is also likely to be related to their personal cost appraisal. This cost includes not only the accountability of their students' test results but also the amount of time, energy and the difficulty or inconvenience involved in acquiring resources. If they perceived their personal cost of using the problem-solving approach to be high, they would be less likely to consider it worth their effort. Consequently they would negotiate their idealistic beliefs about using problem-solving science teaching within the existing school structure.

There are several implications of this study for science instruction and pre-service science teacher education. Firstly, merely encouraging pre-service teachers to adopt a problem-solving approach and then sending them into schools will not necessarily hasten curriculum change towards a wider use of this approach. Institutional pressures within the school, especially for beginning teachers, make them vulnerable to yielding to these pressures and abandoning alternative ways of teaching science. Hence there is a need for support from the school. In this respect, science teaching practice supervisors could work closely with the school principals, heads of department, and the co-operating teachers. Secondly, in the placement of pre-service teachers for their teaching practice in schools, it is important for them to have co-operating teachers who are open to new ideas and who encourage experimentation. If there is school support, the pre-service teachers would be more willing to 'take risks' by trying out new ideas such as introducing small innovations in class which may be deviations from entrenched practices. Thirdly, it is important to help pre-service teachers realize that problem-solving skills are not a separate set of skills outside the prescribed school syllabus, but rather constitute an approach toward teaching the content in the syllabus. During the science methods courses in the teacher education programme, more problem-solving teaching strategies addressing specific science concepts could be included to help the pre-service teachers acquire a wider repertoire of discipline-specific pedagogical knowledge. The use of more concrete direct examples would help pre-service teachers see how problem-solving theory can be put into practice.

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GROUP INTERACTIONS IN SCIENCE PRACTICAL WORK

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ABSTRACT

This study explored the interactions of a highly motivated group of students doing traditional practical work in science. Interest focussed on the social construction of understanding and how this could be described. Despite considerable collaboration in constructing an understanding of the task the students rarely focussed on the concepts the practical work was intended to illustrate. Collaboration was described in terms of social behaviours and discourse moves which supported the use of cognitive strategies.

INTRODUCTION

Practical work is almost an article of faith amongst science teachers. It is used for a variety of purposes, the main ones being to illustrate science concepts, to show the scientific method, to motivate students, to teach practical skills and to develop problem solving (Hodson, 1990). However the research literature of practical work in science education reveals conflicting evidence for its effectiveness (Hofstein & Lunetta, 1982; Friedler & Tamir, 1990). This has led to much questioning about the role of practical work in science education and proposals for change (Woolnough & Allsop, 1985; Millar, 1987; Hodson, 1990). Some writers have suggested a need to know more about the processes involved in practical work (Tobin, 1990) and in groups (Solomon, 1987) in order to understand the problems of practical work.

Students doing practical science almost invariably work in groups, usually because of the need to share equipment rather than on educational grounds. Yet the rich research literature on group work has not been widely utilised in science education. Its relevance is clear if we continue to do practical work in groups and it is particularly important if we acknowledge the failure of many groups in science practical classes to achieve what the teacher intends (Tobin, 1986). Solomon (1987) also drew the attention of science educators to the social factors influencing learning, pointing out that science lessons are "a social activity which is governed every bit as much by the rules and rituals of group activity as by the exposition and questions posed by the teacher" (p. 126).

Research into group work has produced conflicting evidence about its effectiveness in relation to learning, although there is consensus regarding the development of social skills. Linn and Burbules (1993) noted the importance of social structure, individual goals and the diverse nature of knowledge construction in determining the outcomes of group work. In a recent "inductive and conceptual" review of group work research, Cohen (1994) has re-focussed attention on the nature of the task and the kinds of group interaction which are productive, suggesting that this is a more fruitful direction for future research.

Cooperation and collaboration are terms often associated with group work. In this study collaboration is taken to mean more than cooperation. Whereas cooperation can mean simply working together to carry out a task, collaboration involves the sharing of ideas. It seems the more appropriate term if we are interested in the processes of group learning. McKinley (1989) describes the collaborative learning process as:

> a discussion in which learners cooperate in identifying and exploring the nature and perceived adequacy of each other's perceptions, opinions and beliefs in a given area of study. The purpose is to help each other identify and examine the nature and bases of their understandings and the possibilities of alternative views. The purpose is not to persuade, to inculcate, or to seek a group consensus about "truth", for collaborative learning has nothing to do with producing a congruence of opinions on a subject or a concept.

This study arose out of both the practical science and group work literatures, which currently call for a focus on the processes and learning mechanisms of groups. The purpose of the study was to investigate the nature of group interactions during science practical work, with a particular interest in how these processes facilitated or inhibited the learning of concepts and the group construction of understanding. The study also aimed to investigate the applicability of a model for analysing and presenting data obtained from a study of group interactions in the laboratory context.

DESIGN AND METHODS

This study adopted an interpretive design (Erickson, 1986), the central concerns of which include "the nature of classrooms as socially and culturally organised environments for learning" and "the nature of the meaning-perspectives of teacher and learner as intrinsic to the educational process" (p. 120). Focussing on group processes and a social construction of understanding in groups involves both these concerns, particularly the meaning-perspectives of students.

The participants were first year primary teacher education students in a Science Foundations course which aimed to improve the students' understanding of basic science concepts. The group invited to participate had been working together for nine weeks prior to observation and were chosen for their commitment to learning through practical work, their high level of interaction and the composition of the group. The group included two recent school leavers (Cherie and Cassandra) who had completed science subjects to Year 12 and two mature-aged students (Marcia and Julie) who had no previous school experience of science. It was expected that this combination of students might throw interesting light on the culture of "school science" as the older students were introduced to it by the younger ones. It also provided the situation of differing levels of science ability between members which, according to Webb and Kenderski (1984), was more likely to lead to high level elaboration.

The principal data source was videotaped observation of the group during four hours of practical work over two laboratory sessions. Sources of triangulation for interpreting the videotapes included a group stimulated recall discussion of one of the practical classes, a group interview (focussed on ideas about the purpose of the activities and the students' views of science practicals and group work), the laboratory manual, the students' practical reports, videotape of the teacher's introduction to the classes and whole class discussion during and after the activities. Students were interviewed individually eight weeks after the data collection. In this interview they were invited to respond to the assertions derived from the preliminary analysis and to talk about their views of science and science knowledge.

Barnes and Todd (1977) carried out a study of 13-year-old students discussing set topics (mostly non-science) in groups. Using a grounded theory approach, these researchers described the behaviours they considered constituted a social construction of understanding. These behaviours included social skills and discourse moves which they believed to be essential for carrying out cognitive strategies in a social situation. In order to explore for a social construction of understanding in this group's interactions, evidence of these social skills, discourse moves and cognitive strategies were sought in the transcripts of the videotapes of the students doing their practical work. Since the students here were performing practical tasks it was found necessary to add to the behaviours Barnes and Todd described.

The main aim of the practical activities was to illustrate basic science concepts. In the first laboratory session observed these concepts were phase changes (evaporation and sublimation particularly), mass and weight. The second laboratory session focussed on sound waves and their characteristics. In both sessions particle theory was intended to be used to explain observations. Evidence for concept learning was sought in the form of explicit reference to these concepts in the interactions, in the practical writeups and in what the students said about their learning of concepts.

As in any qualitative study the richness of the data is lost in such a brief report and many interesting questions were raised which can only be referred to here in passing. Where extracts from transcripts are used this is with the permission of the students, who also gave approval for their real names to be used.

RESULTS AND DISCUSSION

Using Barnes and Todd's categories of behaviour described earlier we will demonstrate that this group of students did work collaboratively on constructing an understanding of the tasks. However, while the group members possessed and demonstrated the necessary social skills and collaborative discourse moves, the resulting cognitive strategies showed a low level of cognitive engagement with, and focus on the theoretical concepts relating to the practical during the practical activity.

Social skills

Barnes and Todd described three main social skills essential to collaboration: controlling and monitoring progress through the task, supporting each other and dealing with competition and conflict. Examples from the transcripts of each of these skills are presented below.

Controlling and monitoring progress through the task. Controlling and monitoring progress through the task was shared. Julie and Cherie took most responsibility but Marcia also contributed, usually checking on progress by asking questions of the others. Cassandra rarely spoke regarding progress but said in the group and individual interviews that she was involved in the proceedings and felt free to contribute and to disagree. When asked she was always aware of where they were up to and what needed to be done. In the following extract Cherie was controlling progress through the task in the first practical class.

> Cherie: You have to go measure the weight of the lighter thingamejig. Did you measure the mass of the cigarette lighter?
> Julie: Yes, and it is 16.2.
> Cherie: Okay, so now what do we have to do is...

In a study of group science learning Basili and Sanford (1991) observed that leaders emerged in each group and that poor leaders prevented effective discussion. In this group leadership responsibility was shared rather than being dominated by one person. This may have accounted to some degree for the group's success in collaboration on the tasks. Further, this sharing of responsibility was supported by "group perspectives". A group perspective can be said to exist if (i) all members of the group (ii) volunteer information on the perspective in (iii) naturalistic circumstances and (iv) if this information is corroborated by observation and documentation. The credibility of the existence of a group perspective can be increased further by having the subjects vet the analysis (Woods, 1986). Each of these conditions was met in this study, including having the students confirm the group perspectives. Their group perspectives included a belief in the importance of learning science through practical work and through group discussion. For example, the following extract from the group interview expresses their common view of the value of practical work.

Interviewer: Cherie, did you feel that your understanding of any of those concepts was improved by doing the practical work?
Cherie: Definitely. It's the only way I can learn science. I can't learn it theoretically. I could memorise it but that's not going to tell me how to apply it. And that's the same with any subject really for me. If I don't have practicals there to show me concrete stuff, I'm lost. I mean, I understand all the mathematics side of it but I have to be able to visualise what we're doing.
Julie: Yes, yes!
Marcia: Yeah. I would be completely and utterly lost without the practical side of science because I don't learn anything unless I can see it. (Cassandra nods.)

Supportive behaviour. Barnes and Todd described the following supportive behaviours: explicit agreement, explicit approval of others, expression of shared feeling, naming and referring back (to someone's earlier contribution). In this study it was felt necessary to add two behaviours to these: the consistent answering of each other's questions and patience in explanation. These are both forms of implicit approval. All of the above behaviours except "referring back", were observed in the group's interactions. Naming occurred frequently but will not be discussed further.

Explicit agreement. Explicit agreement occurred frequently. For example:
Cherie: Was that right?
Julie: Yes!
Cassandra: Yeah because you're finding a ratio.

Explicit approval. Three of the students were very vocal and the fourth student Cassandra was very quiet, often taking the role of recorder. The other three students gave explicit approval to each other and to the quiet student. In the following extract Cherie complimented Marcia on her contribution.
Cherie: Did you hear what Marcia said?
Julie: No.
Cherie: That was a really good point.
(Cherie then restated what Marcia had said.)

Implicit approval. Consistent answering of questions and patience in explanation were frequently observed for all group members. For example, in the following extract Cherie gave the two forms of implicit approval to Julie.
Julie: Now it says here (reading) "Remember to identify the manipulated variables. Now in each case what is the variables that we changed?"
Cherie: Shortening and lengthening of the string was the variable in (a)...
Julie (writing): Yeah
Cherie: The variable in (b) was the tension, which is, using the Newtons...
Julie: So the first one, we shorten and lengthen the string by the bridge?
Cherie: Yes
Julie: Yeah. And (b)?
Cherie: Was the tension.

Expression of shared feeling. There was much shared feeling in the group. Humour was the feeling most commonly expressed. All four students laughed easily over small incidents and their mistakes, and on several occasions this was important in helping them through difficulties. Enjoyment was also very evident and the students were very curious and interested in the phenomena they were observing. On one occasion the students used dry ice which they had been given for a specific activity, to set up a further investigation of their own. The students also talked spontaneously about the phenomena during the stimulated recall session, expressing their shared fascination with what they had observed.

Cherie: I like the little bubbies, I reckon it's good.
Julie: Yes, and look at the formation, they're not just going straight up...
Marcia: Yes they go ziggyzaggy.
Julie: ..they go zigzag, but twirling at the same time.
Marcia: Yeah.
Julie: Yeah twirling at the same time. I wonder if that means anything?

Dealing with competition and conflict. The students also showed evidence of the third social skill of dealing with competition and conflict. There was little overt conflict and it was usually related to procedures. On each occasion a potential conflict between two students was avoided when a third person joined in and her contribution was accepted as a resolution of the disagreement. The credibility of this claim is enhanced by the researcher having been involved in the class as a teaching assistant for the whole semester and not having perceived any changes in the group's behaviour on the occasions when they were being videotaped. It is therefore considered unlikely that awareness of being videotaped may have influenced the students' behaviour in relation to conflict.

Discourse moves

In addition to the above social skills, the students showed an ability to carry out the kinds of discourse moves described by Barnes and Todd as essential for sustained discussion and the facilitation of cognitive strategies. These moves were eliciting, extending and qualifying. Eliciting refers to requesting someone to (a) continue what they are saying, (b) expand on a previous remark, (c) provide support and (d) provide information. Extending involves taking up an idea and building on it. Qualifying, which can be seen as a form of extending, means modifying what someone has said, perhaps limiting its range or pointing out complexities not considered. Extending and qualifying together can be considered the basis of collaborative dialogue. Barnes and Todd noted that for effective collaboration contradictions need to be seen by others as qualifications so that productive discussion rather than argument follows.

All these discourse moves were used by the group but to a limited extent such that discussion was sustained only for short periods of time. This is probably linked to the students' focus being on the task rather than the concepts which the practical activities were intended to illustrate, which presumably would have generated lengthier discussion. In the following extract the three kinds of discourse moves are evident.

Marcia: So the water is actually going to come out of here (pointing to cylinder) into this (pointing to the water in the water bath)?

(Marcia initiates the topic by raising her concern about what will happen.)

Cherie: Must do.

(Cherie responds, agreeing with Marcia's view.) The discussion would end here if Marcia and Julie did not simultaneously extend on Marcia's original statement thus:

Marcia: I mean this is going to fill up to here with gas and the water's going to come back out.
Julie: And that's why you couldn't have...
Cherie: What do you think Cassandra, do you think it's like going to go down to the 200?

(Cherie elicits support or an opinion from Cassandra.)
Cassandra: Yeah it'll go down.
(Cassandra responds, accepting Cherie's view.) This would be the end of the discussion if Cherie did not then begin to qualify her first interpretation thus:
Cherie: Do you reckon? I don't know. If we're sticking it up here (gesturing upwards) from the ...., you'd think it'd rise (gesturing upwards), I mean but where else could it go? Cos I mean it's stopped (pointing to the sealed top of the cylinder).
(Cherie seems to realise that her first explanation works.)
Julie: Okay *(Everyone has agreed, thus the discussion ends.)*

Consensus regarding observations

The students also negotiated consensus regarding their observations of phenomena and procedures. This was not observed by Barnes and Todd because their students were not doing practical tasks. Therefore, this is an additional category of behavior derived from this study. For example, while they were watching a piece of dry ice placed on water:

Julie: Yeah but how cold is the water, does it, it doesn't change the water temperature that much.
Marcia: Not really.
Cassandra: Is that cold water is it? (feeling the water in the beaker)
Marcia: No it's just out of the tap.
Cassandra: It feels cold though.
Cherie: It feels cold to me.
Julie: Yeah, don't you feel like Einstein? (Cherie & Marcia laugh. Julie feels the water in the beaker.) Yeah that is getting colder.
Cherie: Yeah I thought it was.
Marcia: Yes it is.

Negotiating observations is a vital aspect of group work in practical science which has been noted earlier by Wallace (1986) and Solomon (1989). Traditionally observation is expected to lead to concept understanding, thus if students are to work together towards this they need to agree first about what they are perceiving.

The social skills and discourse moves of collaboration and the ability to negotiate consensus about observations were evident in the discourse of all four members of the group. In the next section the cognitive strategies facilitated by the social skills and discourse moves will be discussed.

Cognitive strategies

The following cognitive strategies observed by Barnes and Todd were sought in the group's interactions: constructing the question, raising new questions, setting up hypotheses, using evidence and expressing feelings and recreating experience.

Constructing the question. When a question is asked or instructions are given to students, they must interpret them using what they already know and what they perceive to be the teacher's intention. This is what is meant by "constructing the question". In doing science practical work this process includes making sense of the instructions in procedural as well as conceptual terms.

In each of the six activities observed, the students immediately began to carry out the physical operations without any discussion about the purpose of the activity or what it meant conceptually. This did not necessarily mean that they understood the task, because at a later stage they would sometimes reveal to each other that they were not sure of what it was all about. In two activities constructing the question and constructing the answer were indistinguishable since it was not until the end of the pratical activity that each of the students arrived at an understanding of what they were expected to do. On both these occasions their construction was at odds with the teacher's intention regarding the task. In one case, using a sonometer to investigate variables affecting the pitch of a sound, two of the students' experience with musical instruments gave them quite different understandings of terms used in this scientific context. This showed how everyday experience can influence this process. For the other four activities the students were successful in their interpretation of what to do and how to do it as evidenced by observations of their actions.

Raising new questions. If students raise questions of their own this suggests that they are cognitively engaged. In the constructivist view of learning raising new questions indicates the accessing of prior knowledge and experience and becoming actively involved in constructing understanding. Here procedural questions are not considered "new" questions.

Most of the questions asked were procedural ones. Almost all of the non-procedural "new" questions asked were raised by Marcia, one of the mature-aged students. These questions were about the phenomena, reasons for procedures and science conventions, and on a few occasions only, trying to make links with concepts. Except for the few questions making links with concepts, Marcia's questions usually resulted in discussion, which illustrates the potential for learning when new questions are asked. The two older students, Marcia and Julie, were keen to make sense of the tasks and valued the group interactions in achieving this understanding . In the group interview, Marcia described the importance of asking questions and having them answered by the group:

> If we couldn't work as an interacting group like that, if I was working in a group where these people really knew what they were doing but were very dominant in what they were doing - they would just do it, write down their results and they would go home and they would understand what they'd done - I would have absolutely no understanding. You'd just stay on the same level. If they're not prepared to answer your questions and work as a group then you would never, never catch up.

The process of the asking and answering of questions in a group is considered in some detail by Webb (1989) in her model of peer interaction and learning. She noted that how students' questions are answered is a vital factor in learning. In this group although questions were always answered, and with much patience, the recent school leavers invariably responded to the mature aged students' (few) questions about concepts with quantitative, rule-based answers. This could have been a factor contributing to the lack of conceptually oriented discussion. For example:

> Marcia: What would that have to do with pressure?
> Cherie: Well pressure's little um, rule, is force over area.

Setting up hypotheses. Verbal evidence of this strategy was found only on two occasions, in an activity which specifically asked students to do this with the question, "How might you improve the efficiency and clarity of your string telegraph?" In response to this question two hypotheses were formulated and tested.

Using evidence. The use of everyday knowledge or given information to help understanding or to solve a problem was interpreted as using evidence. Both kinds of evidence were used by the group. Not surprisingly, the mature-aged students who had not previously studied science verbalised everyday experience to help them make sense of the phenomena. In comparison, the recent school leavers looked for evidence within the information provided in the laboratory manual. Doubtless, the school leavers were sometimes searching their own knowledge base but this was not verbalised. Only occasionally were observations used as evidence by either group of students to help their understanding or to solve problems.

On the whole, evidence was not used very frequently during the classes observed, possibly because evidence is part of argument and while procedures are the focus of attention there is little need for it unless some difficulty arises. Less structured activities would probably lead to more need for argument.

Expressing feelings and recreating experience. As discussed previously, there was much expressed enjoyment and humour in the group. Further, as the students (mature-aged in particular) frequently made links between the practical activities and their personal everyday experience, both the enjoyment of the activities and the engagement of their prior experience, together enhanced the probability of a reconstruction of that prior experience (Pintrich, Marx, & Boyle, 1993).

The collaborative behaviours and cognitive strategies described were used by the students in understanding their tasks. Evidence for a focus on the relevant concepts was sought in the students' interactions, in their practical reports and in what they said in the group and individual interviews. On only a few occasions did the students explicitly refer to the concepts associated with the activities, the major focus being on procedural steps and the phenomena being observed. All four students indicated that time pressure to finish the activities was the reason they did not focus on concepts. On the other hand, the tasks were highly structured, teacher discussion before and during the activities focussed mainly on procedures and practical reports were written up formally as an account of procedures. Each of these factors provides a reason why the students may have focussed on procedures rather than the concepts the practical was intended to illustrate.

CONCLUSIONS

This investigation showed that in a traditional practical context, although students demonstrated the collaborative skills and cognitive strategies necessary for a group construction of understanding, during the practical there was a low level of engagement with, and focus on, the concepts the practical activities were intended to illustrate. Such an outcome supports earlier research questioning the effectiveness of traditional practical work in the teaching of concepts (Woolnough & Allsop, 1985; Hodson, 1990).

Yet the students in this study believed quite strongly that practical work was vital to their understanding of concepts. Is practical work able to offer more than engagement at the level of procedures and observations? Approaches which provide time for discussion and reflection, links with everyday life and students' prior knowledge and a more explicit focus on the concepts or main ideas of science offer a new direction for practical work. Reflective rather than formal writing about practical work is another option that may facilitate conceptual learning from practical work. Another option is to change the nature of the tasks. Both practical work and group work literatures suggest that tightly structured tasks do not necessitate the discussion of ideas and the use of cognitive strategies such as raising new questions, hypothesising and using evidence. More open or problem solving tasks may facilitate the use of such strategies (Cohen, 1994).

As researchers begin to focus more on the group processes involved in practical activities, there will be a need to develop and to evaluate models for analysing and presenting the data obtained from this context. This study has shown that with the additional behaviours described, the social skills, discourse moves and cognitive strategies in the model developed by Barnes and Todd for analysing discourse are applicable to practical work.

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TEACHING PORTFOLIOS: DEVELOPING QUALITY LEARNING IN PRE-SERVICE SCIENCE TEACHERS

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ABSTRACT

The premise that underlies the pre-service science teacher education program at Monash University is the need to focus on the nature of learning in ways that encourage student-teachers to reconsider their conceptions of learning and how this relates to their view of teaching. The purpose of teaching portfolios is to act as a prompt for student-teachers to reconsider these conceptions and as a way of helping them to better articulate their professional knowledge. The Science (Stream 3) student teachers construct a portfolio of teaching strategies, episodes, ideas, etc. that demonstrate how they see their role as science teachers. The portfolio is ungraded, open-ended and organised as a dynamic assessment task, not just a static end product. This paper reports on student-teachers' understanding of, and approach to portfolios as they come to understand its purpose and value.

INTRODUCTION

All students undertaking secondary school science methods (Biology, Chemistry, General Science and Physics) in the pre-service education program at Monash University participate in an integrated program known as Stream 3. Stream 3 is designed to encourage students to reflect on their perceptions of themselves, their science knowledge and their notions of teaching and learning in science (Gunstone, Slattery, Baird & Northfield, 1993). Numerous activities are undertaken to encourage this. They include visiting primary and secondary schools, teaching on a 1:1 basis, teaching in small groups and working with Year 7 students in an outdoor setting through participation in a science camp. They are also placed in situations where their understanding of content is challenged so that they can reconsider their own science learning. The program also endeavours to model teaching strategies in context for students with the expectation that this will help participants better recognize the value of different approaches to teaching if they experience them as genuine learners, rather than simply being told about them. Students meet weekly in tutorial groups and throughout the year move through a semi-structured program designed to expand their understanding of teaching and learning science. The development of teachers as reflective practitioners is therefore a primary tenet of the Stream 3 course, and all aspects of the course, including assessment, are designed to embody this philosophy. In an attempt to further enhance student-teachers' thinking about and practice of reflection, teaching portfolios were introduced. The use of teaching portfolios was seen as one way of helping student-teachers to better articulate their view of what it means to be a science teacher. We use teaching portfolios as an assessment procedure but they are an ungraded task and as such perform a summative role as they are specifically designed to encouraged divergent learning and therefore a range of products. This paper outlines some of the research into the implementation of teaching portfolios in the Stream 3 program and its perceived value to student-teachers.

What are teaching portfolios? As Bird (1990) points out, teaching portfolios differ from the traditional notion of portfolios from areas such as architecture and photography because they are not just a collection of examples of one's work. The teaching portfolio is based on the subsequent learning from experiences, thoughts and actions about teaching and learning that are then the precursors to the formation of the items contained in the portfolio. The structure of portfolios is not fixed as they consist of a variety of items such as diagrams, concept maps, overviews of unit plans, photographs, teaching situations etc. so that in an interview the creator's philosophy of teaching and learning may be better understood and conveyed to the interviewer (e.g. a prospective employer).

Our work into the use of portfolios supports other research findings which suggest that as an assessment tool, portfolios demonstrate an ability to capture and convey the complex nature of teaching and learning (Barton & Collins, 1993; Shulman, 1987, 1988; Wiggins, 1989; Wolf, 1989, 1991). As Shulman (1988) points out, this is because "In general, performance assessment exercises can reflect the complexities of teaching more faithfully than do test items" (p. 38). Well-constructed portfolios can help to bridge the gap between assessments that introduce realism of performance as well as reflecting the teacher's working environment. We believe that this is largely due to the fact that portfolios give a student an opportunity to take responsibility for his/her learning. Although a teacher may set broad parameters for the portfolio, it is the student who decides what to include and, more importantly, what the contents mean. Making these decisions requires introspection and encourages students to focus more clearly and directly on their learning (Garman & Piantanida, 1991, p. 2).

Creating opportunities for student-teachers to take responsibility for their own learning and to reflect on their experiences is then fundamental to the successful implementation, and use of, teaching portfolios if they are to be valued as more than just another task in the Diploma in Education program.

In the Stream 3 program at Monash University we describe teaching portfolios as visual representations of one's philosophy of what it means to be a science teacher. One intended audience for the portfolio is a prospective employer. In this sense portfolios are an "end-product", a thing to be created. However, it is the creation process that encourages quality learning to take place and is the foundation to the final products. This creation process is drawn from the learning that the participants experience when their understanding of science content is challenged. This leads them to reconsider their understanding of the concepts involved in that content area. It is intended that this approach to learning about learning will influence their teaching practice so that the link between teaching and learning becomes more explicit. In so doing, reflection on this process influences what they consider is appropriate as a way of visually representing their learning to others through their portfolio items.

Therefore, the teaching portfolio is intended to contain items which may be used by student-teachers in an interview. Well-constructed items should then act as a prompt for individuals to articulate their understanding of teaching and learning and give the interviewer an insight into the interviewees' thoughts and actions about the complex nature of teaching practice. Our research over the past two years demonstrates that developing this understanding with student-teachers requires considerable time and is unashamedly linked to the quality of learning the individuals experience.

RESEARCH METHOD

In 1993, all Stream 3 students (n=30) were required to produce a teaching portfolio as a course requirement. This was the first time this task had been used as a means of assessment for all Stream 3 students. As an assessment task, the portfolio is an ungraded, open-ended, divergent task designed to encourage students to creatively develop ways of displaying their understanding of teaching and learning science to others.

The research reported in this paper is based on these students' understanding of portfolios. Data were collected from interviews from a small group of students (n=8) who volunteered to be interviewed throughout the year. These volunteers were representative of the larger Stream 3 group as they came from the range of science subjects offered and reflected the gender composition of the group as a whole.

Interviews were conducted twice, first mid-way through the course and again just prior to the end of the year. Interviews were conducted by independent researchers who worked through a semi-structured interview protocol (Box 1) designed to determine the students' understanding of the Stream 3 course, its assessment procedures, and their view of the portfolio task. The use of research assistants was also one way of diminishing the likelihood that participants would feel obliged to tell us what they thought we (as their teachers) might want to hear.

BOX 1: THE INTERVIEW PROTOCOL

1. How do you feel the Stream 3 program is going? What do you think of it?
2. How would you describe the Stream 3 approach to teaching and learning?
3. Can you think of any examples of teaching and learning that you think are interesting from the Stream 3 program?
4. What were expectations of Dip.Ed. before your joined the course? How do you think they have changed? Why?
5. What do you think the course should do for you? How should it change?
6. What have you found most beneficial in the course?
7. What ways have you learnt through the Stream 3 program?
8. What is the Stream 3 approach to assessment? How do you feel about that?
9. What are the Stream 3 tutorials like? How do they affect your view of learning to teach science?
10. What would you see as the strengths and weaknesses of Stream 3?
11. How have you found the portfolio task?
12. How are portfolios approached in tutorials?
13. What sort of products are you producing?
14. What is the purpose of portfolios? How would you describe the portfolio to someone else?
15. What value do you place on the portfolio?
16. What do you think is the point of portfolios?
17. How do portfolios fit in with Stream 3, assessment, teaching and learning?

Data were also collected via an open-ended questionnaire completed at the end of the course by 22 of the 30 Stream 3 students. The questionnaire (Box 2) was administered at the end of the course after participants had received their final assessments. It was anticipated that this would also help to disassociate portfolio evaluation and student assessment so that a broader understanding of participants' views of portfolios, and the value they placed on the experience, could be obtained.

FINDINGS

The focus of the portfolio was for the students to consciously develop and articulate their philosophy of what it means to be a science teacher. Students had to link many different ideas, some they had brought with them to the course, others they had developed throughout their pre-service year. It required them to make judgments about these ideas, and the value

BOX 2: PORTFOLIO QUESTIONNAIRE

SECTION 1: The Process of the Teaching Portfolio
1. When did you start working on your portfolio and what prompted it?
2. What were your expectations of the teaching portfolio?
3. How would you describe your approach to the teaching portfolio? (Did you take the task seriously?)
4. How would you describe the value of the process?
   (a) Was the teaching portfolio a valuable process?
   (b) Is it worth doing? Why?
5. (a) What did you see as the role of the Stream 3 tutorials?
   (b) Is this appropriate? What suggestions would you have to improve the process?

SECTION 2: The Teaching Portfolio - the Product
1. What did you include in your teaching portfolio?
2. Why did you include the things mentioned above?
3. How did you go about organising your teaching portfolio?
4. What role do you see the portfolio having?
5. Have you used the portfolio in any way? Explain.
6. Do you see the portfolio having a role in the future? Explain. (Why/Why not?)

they placed on them so that as they reflected on their learning some ideas were either modified or discarded. In this case, reconsidering their own science content knowledge was the context for reconceptualising the process of learning.

Interview findings

As an open-ended assessment task, the creation of a teaching portfolio encouraged diverse options for students which enabled them to produce a portfolio that specified their individual view of teaching and learning in science. However, being so open-ended presented problems for the students as they struggled to understand how to complete the task. The majority initially thought the portfolio should be a collection of resources that could be gathered throughout the year so that on completion of the course they could simply "bundle them together". These views shifted over time as students began to understand how reflecting on their learning could influence their thinking of the portfolio process. As one student noted, "It's helped me organise my learnings from Stream 3 and methods (teaching disciplines) under one umbrella."

It was not until the students linked the notion of presenting their views on their learning to another person (e.g. a prospective employer) that a better understanding of the task began to emerge. Being placed in situations where they began to articulate their view of learning helped them to better explain their understanding of their approach to teaching.

Throughout the interviews it was increasingly apparent that there was a gap between the students' thinking and doing in terms of portfolio production. If an individual had not attempted to produce a portfolio item then there was a sense of confusion about what to produce. The portfolio process was seen as separate from the portfolio product because the explicit link in thinking about the learning and teaching had not been made. Until a situation arose where it was necessary to reflect on one's experience (by producing an item) the notion of a portfolio was an abstract concept. Once work on a product was initiated a better understanding of the portfolio developed. The following quotes are indicative participants' views of this:

> Ellie: It is so I look at things done in science...and pick out various incidents and put them in the portfolio under some sort of title and say what I have learnt from it, indicate what I have done and what I have achieved, what I learnt from it and what it meant to me, and how it will impact on my teaching in the future.
>
> Bruce: If you have a reason for doing something you can actually point it at that reason. If you have no reason to do it, it just becomes an onerous piece of work with no meaning ... now that I understand the task, there is a point and it is worthwhile.

Portfolio development is a dynamic task as the episodes, opportunities for learning that the students' experience throughout the pre-service year "colour" and give definition to their philosophy of what it means to be a science teacher. For example, tutorial sessions were important so that students could link the notion of the 'process and the product' of portfolios.

For the students to explore their thinking and learning, they needed opportunities to formulate their views and to try them out with others. To foster this, the processes of the tutorial sessions were seen as a way of helping them to modify, adapt and adjust their ideas through sharing them with others.

> Irene: ...they [tutorial sessions] make you think. If teachers just tell you something, it doesn't make you think...strategies used in Stream 3 are meant to help me as a learner as well as a teacher. The point of the tutes [tutorial sessions] is to share experiences and learn from them.

It is likely then that a good understanding of the portfolio task would not evolve if the participants were not given opportunities to reflect on what they had done and learnt from their experiences. We viewed tutorial sessions as essential for this to occur as we were able to help individuals grapple with their learning about teaching and learning and to reflect on these experiences. Through this they could process the ideas that they had and to conceptualise their developing understanding of their approach to teaching and learning science.

Questionnaire findings

Students' perceptions of the portfolio task (Box 2, Q.3) shows that only 20% of the respondents saw the task as useful and took the task seriously from the outset, e.g. "My aim with the portfolio was to produce something of a standard suitable to be used in a job interview - I took it very seriously." The low percentage offering such responses is explained by the fact that 50% were initially confused by the task. They struggled in their approach to the task as they did not fully understand what was intended. When this problem was overcome, they then approached it with more enthusiasm and took it more seriously.This understanding of the task is an important point as shown by Q.4 (Box 2). Responses to this question demonstrated that the portfolio task was seen as a valuable process by most students, but only when they fully understood the task. Only two students did not see the process as valuable. The majority commented on the usefulness of the portfolio task for encouraging "reflection on the course", presenting "views on teaching", reviewing "things learnt during the year", and formulating "goals for the future".

Most students viewed tutorial sessions as a means of broadening their ideas about, and strategies for teaching and learning science (Box 2, Q.5). These were also seen as good for discussing ideas encountered throughout the Stream 3 course. In this sense, the portfolio is a partly shared/communal activity, suggesting their learning extends to all members of the group and not just the presenter. The size of tutorial groups was seen as important by two respondents as a diminished size in tutorial groups ($n<8$) led to less opportunity to interact and learn from each other. This highlights the importance of interaction in learning as the tutorial sessions were designed as genuine learning experiences for participants whereby their initial conceptions of science content knowledge was challenged. Hence, de-briefing after a session was important from both a teaching perspective (especially so for the presenter) and from a learning perspective (the participants). Using these sessions to then reflect on the experiences was part of the process of portfolio development.

Our intention was that through this process, an individual's final portfolio items would be constructed by reflecting on these experiences. Therefore, we thought a good portfolio item would act as a prompt to the learning through these processes and be a stimulating visual representation that would encourage an interviewer to want to know more about the student-teacher's thinking. Although this was difficult for student-teachers to understand before they had experienced both the process and the product aspects of the portfolio, it was interesting to note participants' responses of the product. The questionnaire probed perceptions of what the final portfolio represented and included:

* The portfolio is made up of things I've done, things I've seen and things I'd like to try.
* It's a good way of showing [a prospective employer] what you know/understand.
* It's an insight into me as a person and as a teacher.
* It shows that I am still developing skills and gaining knowledge that will benefit my career.
* Because my view of teaching is that people learn in many different ways, content must be presented and investigated in many different ways, my portfolio tries to show that.

Students saw portfolios as having two important roles, one was as a tool to take to an interview to promote themselves and have some control over the direction of the interview, another was that of showing what they had learnt about learning and teaching in science.

Independent Learning

Portfolio use in the Stream 3 program was also designed to reinforce the idea of students developing responsibility for their own learning, becoming independent learners with respect to their own teaching and learning. It is therefore interesting to consider the range of views about what it means to be an independent learner which were suggested during the interviews.

Irene: ...you do not expect the teacher to do everything for you, to think for you, tell you what to learn, tell you what to pay attention to...I think it is students [who] start to think about wanting to know more, want to know other things.

Stan: Presenting the learner with something and getting them interested in it so it's not you [the teacher] making them learn, it's them wanting to learn. Once they start wanting to learn they start asking questions and the drive for learning is coming from them and not from you.

Ellie: A critical approach to the information which is offered to you.

Strangely, students found it difficult to articulate how a knowledge of what it meant to be an independent learner would influence their own practice even after stating that the teaching strategies adopted in Stream 3 were designed to foster independent learning. A good example of this was the way that many interviewees thought that independent learners question what they are doing and make links between different experiences and pieces of information, yet this is exactly what students initially found difficult to do with their portfolios. Until they started to construct an end-product, the (apparently) abstract nature of the product task made it difficult for them to apply such strategies to their own learning experiences. They were not consciously linking their learning from one context to another.

This encapsulates what we see as the paradox of portfolio production. It is difficult for an individual to imagine what to produce until they review their own learning and experiment with ways of articulating this to others. The process of producing a portfolio fosters independent learning but students do not recognize this until they start to construct an end-product. It takes some time for students to recognize the difference between producing a portfolio item that reflects one's achievements and an item that is an insight into one's thinking.

CURRENT AND FUTURE DIRECTIONS

The use of portfolios in Stream 3 is still developing. Two main areas being investigated further (at time of writing) are the impact of teaching portfolios on prospective employers and how to resolve the paradox of portfolio production. Research into the first area is currently under way where we are attempting to gain insight into how useful portfolios are in interview situations and how they are perceived by employers. We have organised interviews for all of our 1994 Stream 3 students with practising science teachers in order to help the student-teachers explore ways of using them in an interview so that we can learn more about how interviewers respond to the portfolios.

Addressing the paradox of portfolio production is also under way. The 1994 Stream 3 students were introduced to the idea of teaching portfolios by explaining that the portfolio should be seen as a visual representation of their view of what it means to be a science teacher. It was introduced with the emphasis on it as a product that they could take to an interview for a teaching position. Examples of some portfolio items that previous students had prepared were also presented at this stage. To introduce the importance of the process involved in portfolio production, students were given the experience of having an area of their science content knowledge challenged. They were put into a learning experience where their understanding of a concept (force) was tested by making predictions, observations and explanations about the concept in different contexts. At the conclusion of this teaching sequence students were asked to represent what they had learnt from the experience in a one-page format as a homework task. There were no restrictions on how to represent what they had learnt other than the one-page limit. We (their teachers) also produced a one-page item demonstrating our learning. In the next session, we were all required to work in pairs and with that partner, to attempt to articulate our understanding of our learning by using the portfolio item as a prompt to that thinking.

This process generated a session that contained a "buzz" of excitement and motivation among students as we explored our understanding. It was one of those sessions that was truly educative. Students then went home and modified their representations according to the feedback they had obtained from their peers. The value of the process involved in portfolio production became immediately apparent to those involved (staff and students) and we think that this is one valuable way of addressing the paradox of the portfolio. We now look forward to continuing this work so that the links between quality learning and quality teaching become much more explicit for the students as they come to better understand the use and value of portfolios.

CONCLUSION

The use of teaching portfolios in the Stream 3 program at Monash University is a deliberate attempt to foster independent learning about the teaching process. The learning is intended to result in developing knowledge that is meaningful and useful to the participants. To do this portfolios are prepared in a very supportive environment that allows students time for reflection, experimentation and risk-taking in their teaching and learning. It is hoped through this approach to portfolio development students will have a greater understanding of the process of learning. If so, then they will also have had the opportunity to make more explicit the links between this and their understanding of teaching. The articulation of their ideas on these issues through their teaching portfolio gives them a good basis for further professional development which we hope will continue throughout their teaching careers.

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FROM SCIENCE TEACHER TO TECHNOLOGY FACILITATOR: A CASE STUDY OF KATHERINE

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ABSTRACT

Technology education has a new focus in New Zealand with the publication of the draft Technology Curriculum. Biotechnology is mostly taught by science teachers in New Zealand secondary schools. This study monitors both the author's and the teacher's evolving perspective of technology education from that of applied science to technology and the influence of the draft Technology Curriculum on this process.

INTRODUCTION

Biotechnology is often used by science teachers to illustrate the application of many biological concepts. Although it has been claimed by the 'science camp', I have been keen to develop biotechnology as an exemplar of technology education. This case study describes and explores the implementation of three biotechnology programmes by Katherine (a practising secondary science teacher) in order to illustrate and reflect on both Katherine's and my changed perceptions of technology education during that period.

Katherine and I embarked on our exploration of technology education in 1992 when she enrolled in my teacher development course, **Teaching Strategies in Biotechnology**, at the Auckland College of Education. We were both experienced educators in science education with degrees in the biological sciences. At that time Katherine had been teaching for 12 years and was Head of Biology in a co-educational state school. She elected to teach a unit that she had developed as part of the course work. At the beginning of 1993 Katherine won a position as Head of Science at a girls' school where the final two programmes were taught.

For three years I have collected data for this case study from various sources, including interviews and discussions with Katherine, group and individual interviews with students and plans which contained objectives, teaching strategies, learning outcomes and evaluations. I also made classroom observations during which I monitored the progress of the lessons as well as the perceptions of the students taking part. Although this case study is Katherine's story it cannot be told without my input. We have spent much time together discussing, reflecting, and team teaching. This paper will:

- describe our changing perceptions of technology education from applied science to technology
- outline the changes in programme organisation and teaching strategies that occurred
- discuss the development of an appropriate biotechnological knowledge and skill base that were perceived as pivotal for effective biotechnology problem solving
- acknowledge and discuss the powerful influence of school-industry links in making biotechnology problem-solving 'real'.

CHANGING PERSPECTIVES OF TECHNOLOGY EDUCATION

In 1992, I considered that science contributed to and formed a basis of technological knowledge. Biotechnology was an example of an applied science which included all the applications of the experimental pure sciences. In fact my views reflected the New Zealand government's perspective i.e. it included technology with science when discussing research and development (Burns, 1990).

At this time I professed to be aware of the ramifications of technology education and wrote about the facets of the discipline and how they affected the teaching emphasis:

> ... when definitions emphasising the products of technology are to the fore, curriculum emphasis is on content. When definitions emphasising processes are dominant the curriculum shifts towards problem solving (Farmer & Hodson, 1991).

However I had not separated science from technology or considered them of equal importance.

My subsequent involvement in the development of the draft New Zealand Technology Curriculum (Ministry of Education, 1993) influenced my views on technology education. I moved from a perception of science preceding technology i.e. technology capability growing out of scientific knowledge to that of a teacher attempting to show the interaction of scientists and technologists (Gardner, 1994). The framework provided by the strands of the draft curriculum has focussed my attention on identifying "real situations which would develop student's technology capability" (Jones & Carr, 1993). The holistic philosophy of technology education underpinning the curriculum, has enabled Katherine and me to develop scenarios which allowed for a multiplicity of outcomes. We were able to create learning situations which posed 'real' problems and provided a context for technology education with a technology rather than an applied science focus.

As a result of this experience I feel that I have developed a clearer perception of the distinction between technology and science. The following definitions and their implications for practice have been heavily influenced by writings of Layton (1993), Gilbert (1993) and to a large extent Jones and Carr (1993). These definitions will identify my stance.

- Science is a process and a set of ideas which have been constructed by people to explain everyday and unfamiliar phenomena (Layton,1993). In practice this means that science is a process which involves the integration of knowledge, skills and attitudes to develop scientific understanding.
- In contrast technology is a purposeful activity aimed at meeting needs and opportunities through the development of products, systems and environments (Jones & Carr, 1993). In practice, when doing technology, the fundamental requirement of the end-point is the operational principle of the 'solution' i.e. how it fulfils the purpose (Layton, 1993). The activity takes place within specific contexts and constraints: the process and the 'solution' are influenced by value judgements.

Katherine's views of technology and science

Originally Katherine's views of technology and science were reflected in the summary statement she gave her class in September 1992: "Science was finding out and experimenting. Technology was making the thing". In 1994 she wrote specific learning outcomes which reflected her broader perspective of technology education and utilised the strands of the curriculum. These were the Needs and Opportunities, Implementation and Reflection, Communication and Knowledge and Understanding strands.

Developing biotechnology definitions

The journey through our perceptions of biotechnology was equally problematic. Initially we limited our definition of biotechnology to the metabolic activity of cells and microbes. In November 1992 Katherine included the following quote in her assignment: "Why trouble to make compounds yourself when a bug will do it for you" (Haldane, 1939). The biotechnology definition she gave her class in September 1992 was "Biotechnology uses microbes and cells from plants and animals to make substances to do work for people".

Over time it became increasingly apparent that our definition needed to be more inclusive if we wanted to include multicellular organisms and organs. I was mindful of the practicalities of limiting biotechnology to microbes and cells and broadened our definition to include organisms and ecosystems: "the utilisation of living systems for the development of processes and products to benefit people"(Ministry of Education,1993).

Biotechnology programmes reflecting our changing technology perspective

Katherine developed her biotechnology programmes prior to and then during the development of the draft Technology Curriculum. The first programme reflected our limited views of technology and biotechnology as is evident in the following summary and flow-charts (see Fig.1). Later programmes demonstrated our changing perceptions of technology and showed how they could be developed within this philosophical framework. The essential features of the programmes were as follows:

Health and Disease: The Mighty Microbe. This unit formed part of a 5th form School Certificate programme (Year 10). The objectives of the programme were to study microbes causing disease and demonstrate their transmission and control. School industry links were established with the diagnostic laboratory at Auckland Starship Hospital.

Kiwifruit Dairy Product. This programme was taught to a 4th form (Year 9) science class in a single sex school. The girls formed a company comprising of four divisions. Each division had a separate responsibility; either developing, producing, packaging or marketing a dairy product. Informal school industry links occurred with the school canteen, supermarkets and delicatessens.

Biotechnology in Action: Soft Cheese Production. This programme was taught to a class of 3rd form girls using a similar class organisation as above. The programme had a technological focus with the development of a system for the production of a soft cheese. School industry links were established with the Anchor Milk factory and the Puhoi Valley Cheese factory.

CHANGES IN PROGRAMME ORGANISATION AND TEACHING STRATEGIES

The changes that occurred in the programme organisation and learning objectives over three years reflected Katherine's altering perception of technology education from one of applied science to a technology focus. Such changes were evident when in December 1993 I asked Katherine to position her first course 'The Mighty Microbe' in a science-technology continuum, she considered it "probably slightly towards the science [end)]". These changes were evident in Katherine's programme development and delivery. There were four major shifts in her teaching style.

From planned teaching of science concepts to knowledge acquisition when appropriate. While teaching 'The Mighty Microbe', Katherine attempted to make science knowledge explicit through explanation and putting the topic in context. She taught technological skills and knowledge before setting up any problem-solving situation (Layton, 1988). In order to illustrate scientific concepts she taught bacterial morphology and metabolism and aseptic techniques. The dairy product and soft cheese programmes were designed so that scientific concepts and technological knowledge were taught on a 'need to know' basis.

Progression from a teacher directed to a student centred programme. 'The Mighty Microbe' programme was organised so that students could rotate through experimental and theoretical exercises. Katherine introduced the unit with a range of teaching strategies. She gathered prior views; modelled technical skills; demonstrated a range of research and comprehension techniques; provided opportunities for experimentation and observations; promoted concept development and organised a school industry visit. Although the students worked in groups the direction and time frame was set and monitored by Katherine.

> The dairy product and soft cheese production programmes were not only monitored by the students but they also decided on the product they would produce. After an initial period of exploratory activities which introduced and outlined the topic, the class were left to run their companies and prepare their product presentation.

Scenario development as a focus for the programme. Development of problem-solving scenarios gave the latter programmes a technological focus. Concept development and a technology skill base evolved in tandem, thus enhancing the student's ability to 'solve' the problem.

Progression from teacher monitored atomistic assessment to holistic assessment using a wide range of strategies. Katherine carefully monitored 'The Mighty Microbe' programme and there was a test at the end of the section. The 1993 and 1994 programmes were structured so that the students were aware of the teacher's expectations via a design brief. Each group was expected to hand in a group report as well as present an oral report to a 'Board of Directors' and in the case of 'Soft Cheese Production' to the manager of Puhoi Cheeses. There was a strong element of self and peer assessment in the programme. The essential holistic nature of the programme and process was emphasised in line with the philosophy expressed in the draft curriculum.

In 1992 I believed that appropriate technological and scientific knowledge acquisition was pivotal to the development of a useful learning situation in technology problem-solving. I still hold this viewpoint although I now recognise the difference between technological and scientific knowledge, both being important in the biotechnological context. I would argue that even more significant is the way in which teachers teach and students obtain that information. My views on how this is developed have changed dramatically.

KNOWLEDGE AND SKILL BASE DEVELOPMENT

The difference between scientific and technological knowledge

If one has an applied science perspective of technology education then scientific conceptual understanding must precede 'doing' technology. At least it must be introduced concurrently for any meaningful technological understanding and development in students. This was my position in 1992 and early 1993. On reflection I realised that I based that on the premise that science was the form of knowledge that was the basis of biotechnological knowledge. Certainly my views of science have changed and I now believe that science is just one of the contributing forms of knowledge in this process (Harding, 1991). This has implications when one considers the link between science and technology education.

An applied science perspective does not give a true picture of technology. Fleming (1989) noted that applied science portrayed technology in "far too passive a light". Thus in order to make the problem-solving core of biotechnology meaningful it is important to identify the important aspects of biotechnological knowledge.

Locatis (1987) observes that both science and technology may involve learning or the accumulation of knowledge but observes that "in science, learning mainly results from experiments, while in technology learning comes mostly from experience". As Locatis observes, there are many similarities between scientific and technological knowledge. For example invention testing and evaluation in technology finds out if the solution is successful, while experimental testing has engineering elements in design methodology. Similarly, methods used in science and technology are "empirical, systematic and based on common sense". During the 'Soft Cheese Production' programme I noted that evaluation testing was an important aspect of the quality control division whereas the production team were following a trial and error format.

Medway (1989) states that at the heart of technology lies in design. Design planning is problematic in biotechnology. At present all I can do is pose a series of questions. Is the elevation of planning over trial and error an appropriate criterion to evaluate a 'solution'? If trial and error is to be dismissed as a sign that students lack appropriate scientific knowledge, when is technological adaptation not considered appropriate and called trial and error? Certainly students were developing expertise and groping their way to a solution which would not have been apparent if they had attempted to formulate a plan. This facet of biotechnology education needs further research and reflection.

The development of a biotechnological knowledge and skill base

In 1992 I frequently voiced my concerns to Katherine about the problem of developing an appropriate knowledge and skill base and I observed that the skill level of students needed to be quite high for students to problem-solve in biotechnology. I listed the skills I thought were important for this development. These were plating, streaking, aseptic techniques, dilution and its significance, transferring cultures and the labelling of plates.

In 1994 I still believe that biotechnology-based problem-solving requires a particular knowledge and skill base in order to provide students with a worthwhile problem solving experience. However I realise that there is another way to achieve this situation besides the pre-teaching of the concepts and skills.

Gilbert (1992) lists the strategies that Layton, Medway and Yeomans (1989), found teachers using in English schools when teaching technology. They were the use of:

- prior general teaching of science concepts
- bespoke teaching- i.e. on a need to know basis
- guided experimentation
- eclectic pillaging of ideas from all disciplines.

Teaching strategies Katherine used to develop a skill base

During the teaching of 'The Mighty Microbe' (1992), Katherine used a mixture of prior general teaching of science concepts and guided experimentation (Layton et al., 1989). She demonstrated and modelled aseptic transfer, plating, subculturing to the whole class and then to smaller groups when it was apparent that they had little understanding of the process. She followed the sessions with intensive teaching and a series of illustrative experiments to give students practice in the technique and its interpretation.

Katherine reflected on the efficacy of the modelling sessions in her written report:

> What a mess! Initially it was too rushed and even the second time there were students who did not get the idea. It is a good technique but needs to be done with small groups and repeated several times. [November 1992].

Katherine also reflected on the effectiveness of an experimental procedure the students were given to practise their microbiological techniques:

> ...although they had written instructions as well as verbal, most groups muddled through not really knowing what they were doing. However, once shown what was required in small groups, most achieved adequate results even if they did not know what their results meant. [November 1992].

Rather than condemning this practice it is important to note that it reflected the teaching strategies that we both thought appropriate and I had used in my teacher development programme. Katherine had also enhanced the process by giving the students a chance to mimic and comment on each stage. We were both surprised at the range of common misconceptions that we identified amongst the students. For example:

- if the bacterial loop was held in the flame and it fizzed, it meant that there was bacteria on the loop
- air bubbles in the agar were thought to be bacterial colonies
- when the loop was red there were bacteria present
- colonies growing on agar plates were thought to be single bacteria [September 1992].

In comparison the quality control groups involved in the production of the 'Soft Cheese' carried out the same procedures as the 5th form class studying 'The Mighty Microbe' and Katherine made the observation that
the research and development group was the one I needed to help the most.... because it was the one that required the most scientific skills ... [February 1994].

When Katherine asked the group what they needed to know, the group decided that the quality control division should investigate the storage temperature for keeping soft cheese; hygiene during soft cheese production; and the sterility of benches and equipment

As a result Katherine discussed and demonstrated plating, the conditions for optimum bacterial growth, antibiotic testing and the use of microbial indicators. It was evident from the students' descriptions of the bacteria colonies growing on the plate that not only had they mastered the skills of plating. In addition these students had understood the concept of and reasons for dilution of bacterial cultures.

> ... they are a bacterial colony - and there are lots of them - but as you go up here they get separated and you can actually count... up here it will be really hard to count each one of these little dots... but down here you can so that is the whole process of that dilution... lots here.... spreading them out. [March 1994].

I would consider teachers to be a technology facilitators when they are able to provide guidance, create opportunities for learning and stimulate students to look for a broader perspective when developing their 'solutions'. Techniques, knowledge and a skill base would be provided when appropriate for the learner. The teacher would provide opportunities for reflection, modification and appreciation of the multiplicity of possible 'solutions'. In my view, Katherine had become a 'technology facilitator'. Further verification of her facilitating style was evident from my diary record of a lesson:

> the groups are busy working either writing up the reports on the computer... doing their production... doing their quality control..... doing the packaging... making the cheese... so there is a lot of group activity going on...Katherine is going round monitoring the groups... [March 1994]

The teaching strategies she most commonly used were teaching on a need to know basis, and guided experimentation (Layton et al., 1989). There was some eclectic pillaging as was seen in the adoption of data history sheets used in Puhoi Valley Cheese Company. Her own perception of her changed role was most evident on a day when she was absent for a period of time. When she returned she commented to me with a smile that "she was redundant".

SCHOOL INDUSTRY LINKS

Gilbert (1992) observed that the science we practise at school does not bear a close relationship to that practised by researchers and why should technology be any different? He also commented that if the intellectual circumstances of science education are different from those practising science, should technology education follow the same pattern? Of course technology as practised in schools cannot mimic 'real' technology but I would argue that the establishment of school industry links may make some aspects 'real'.

Visits by groups of children in the 'Mighty Microbe' programme in 1992 demonstrated that their laboratory procedures were 'real'. One student reported: "I expected people in white coats with gloves on and laboratory bubbling all over.- test-tubes and stuff like that.... but it wasn't like that really...it wasn't like that it was more like our science room." [September 1992].

The establishment of school industry links with Puhoi Cheese Ltd. provided opportunities for the students to develop a wider dimension to their problem-solving experience e.g. the quality control team developed a production flow chart where they monitored the stages and quality control procedures of the cheese making process.

In the classroom programme Katherine developed the soft cheese production programme with the ambition of making the experience 'real'. She visited the factory to familiarise herself with the process, set up the teams by asking the students to formally apply for specific jobs in the school company and invited the managing director of the Puhoi Cheese Ltd to listen to and assess the students' presentations of their process and product. Thus she used school industry links to reduce the divide between technology problem-solving in and out of the classroom.

Hennessy et al. (1993) stated that technology in schools was different from that of the real world of technology. However Katherine's programme demonstrated that it is possible to model some aspects of 'real' technology in the classroom. These included:

- valuing team work rather than individual work in the world of industry e.g. Katherine set up the dairy product and soft cheese problem solving exercises so that team resolutions were expected for assessment.
- developing self motivated learning (albeit linked to commercial gain) as is the norm in industry. Even when the scenario was set by the teacher, there were many instances when the students identified a 'need to know' learning situation e.g. pH monitoring of the process, packaging requirements, hygiene standards.
- demonstrating that the problem is not clearly defined when set in an industrial setting. All of the groups experienced this situation with new questions being asked and new avenues opened for exploration e.g. quality control team, cheese production.

CONCLUSIONS

Our rewarding exploration of technology education has demonstrated that when biotechnology education is taught with an applied science perspective the programme lacks the breadth of the technological facets as identified in the draft New Zealand Technology

Curriculum. I believe contextually based programmes in biotechnology are an effective vehicle for technology education. Factors identified in this study as contributing to the successful outcomes of the programme are: the establishment of school-industry links, the employment of teacher-facilitated, student-centred approach and the development of a knowledge and skill-base that augments rather than defines the programme.

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PROGRESSION IN SCHOOL SCIENCE CURRICULUM: A RATIONAL PROSPECT OR A CHIMERA?

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ABSTRACT

Science in schooling has for the first time been recently considered as a verified whole for the 10 or 12 of its compulsory years, rather than for a limited sector of schooling or for a particular group of students. This has also been occurring as part of a wider review and plan for the whole curriculum of schooling. A framework has been provided consisting of a matrix of strands of intended content for learning across a number of levels approximating the years of schooling. There is a sense and expectation of continuous progression in the learning of science. Earlier notions of progression in science curricula are explored and compared with what has now appeared in the national curricula in England and Wales, New Zealand and Australia. The notions of curriculum opportunity and curriculum purpose for science education are introduced as factors that would lead to a shift in the sense of progression from a focus on Science itself to an emphasis on the learners' changing need of Science as they progress through the years of schooling.

INTRODUCTION

The later 1980s have seen, for the first time in educational history, serious attempts in a number of countries to conceptualise and define science education in relation to the whole of schooling, or at least to the 10, 11 or 12 years of it that are now compulsory or undertaken by all students. In all previous periods of curriculum activity in Science (for example, the era of big projects in the 1960/70s), a curriculum project was concerned with a limited sector of schooling, or even with a particular group of students in such a sector. Nuffield Secondary Science, for instance, set out to provide science education for students in Years 9 to 11 who were not undertaking the academic science studies that led to the English "O" Level Certificate. The Australian Science Education Project (ASEP) had as its charter the science education of all students in Years 7 (or 8) to 10.

In the new situations, a group was established with the task of planning science education across all the years of schooling. Furthermore, this group was only one among a number in each country that were working to formulate a total National Curriculum for the years of compulsory schooling. Each group for a subject or key learning area was given a common framework for expressing its set of intended learnings throughout schooling. I believe that this common framework is not an inevitable consequence of a national curriculum, although it has been used in England and Wales, New Zealand and Australia.

This framework for the intended learning outcomes provides for a number of conceptual and/or process strands (n), the content of which is to be developed through a number of levels (m) that approximate to the number of years of compulsory schooling, but were primarily intended to recognise differential rates of learning by students. The ensuing m x n matrix provides m n boxes into which the content for learning in each learning area is to be fitted.

A rationale for this matrix as the common framework for each subject could perhaps be provided from some generalised theories of knowledge and knowing. Rather, from my experience with four of the eight subject fields of the Australian project, I suspect it was derived in that case much more from a curriculum "bureaucrat-ese" that sought neatness and the simplicity of uniformity in the conduct of eight very large and complex tasks that had to be administered and completed by the same due date. As Phenix (1964), Hirst (1969) and numerous others since have pointed out, the untidy richness and differentiations that characterise the collage of learnings that schooling can encourage seem to have been too uncomfortable for these politically and bureaucratically-driven national projects. The early debates among interest groups, for Science, Technology, and Studies of Society and Environment suggest that none of these would have chosen such a matrix had the initiative been given to each committee to develop its own framework.

Nevertheless, the presentation of the m x n matrix for their task did indicate to the Science group that there was an expectation that there will be a continuous progression in the learning of Science albeit not at the same rate for all students across these ten or so years. To politicians or parents, such an expectation of progression is both attractive and reasonable. Indeed, given the curriculum documents that have been produced in the three countries referred to above, the science writers also espoused, or, at least, bowed to this expectation of progression. In this paper the notion of progression in the learning of school Science is examined.

BECOMING AWARE OF THE ISSUE

My attention to the issue of progression in a national curriculum for Science was finally focussed in 1993 through a commission from the Wiltshire Committee in Queensland to prepare a paper on science curriculum which reviewed school science in that state from about 1980 to the present, and to relate it to contemporary curriculum developments in Science nationally and internationally (Fensham, 1994). Six years earlier, I had been dimly aware of the issue during a workshop at Leeds University, led by Rosalind Driver, a key member of the original Science Committee for the National Curriculum for England and Wales. In this workshop, Rosalind tried to engage a group of teachers, who had worked with her earlier in the Children's Learning in Science project (CLIS, 1987), in the task of defining for a broad topic area like *Properties of Matter* what should be learnt in the first four levels of the ten levels of learning that the National Curriculum project had chosen to correspond to the 12 grades of England's compulsory schooling. I remember how bewildered some of these teachers, strongly committed through the CLIS experience to a constructivist view of learning, were with her questions and tasks which were now asking them to adopt a very definitely, staged-view of learning (Driver, Squires, Rushworth & Woods-Robinson, 1994).

Black, another major contributor to the National Curriculum project in England and Wales, together with Simon (Black & Simon, 1992) described a King's College project on progression. In it, they attempted to draw heavily on the findings from the alternative conceptions studies of the 1980s in order to map a progression of conceptual changes about phenomena from what they called "the learners' country" (their personal knowledge) to "the science country" (scientific knowledge). The map was to be controlled by phenomena, experience of which would act like a bridge for moving students from Conception A to Conception B. Ideally, they argued, if evidence for a series of such experiential conditions can be found, without which learners are most unlikely to move from A to B to C to D, then these science phenomena would be appropriate ones to space through the years of the curriculum. Several other European science educators (e.g., de Vos 1989/90 in the Netherlands and B. Andersson 1989 in Sweden) have also reacted to alternative conceptions by seeking such pre-conditional or decisive phenomena for the encounters students should have in science education at school.

Few teachers of science would wish to deny any idea of progression. Each topic in a science curriculum is taught from some starting point and is intended, over a lesson or a series of lessons, to become more widely experienced, to be expressed in a greater number of ways, and applied in an increasing complexity of situations. What is not familiar is the situation where one of these topics, even a large one like Electricity, is to become an 8 or 10 level sequence of learnings stretching over 10 years in a hierarchical fashion.

HOW PROGRESSION HAS BEEN ASSUMED

The review of the Science curricula that had been in use in Queensland in the primary, lower secondary and upper secondary years since 1980 reminded me how discretely these had been developed hitherto. In each of these sectors of schooling, the notion of progression was different (Fensham, 1994). Nevertheless, how "progression" has been handled within sectors of education nationally and internationally might provide a basis for deciding what is now to progress across 10-12 years. In Table 1 the idea of progression that was influential in a number of the large sectoral science projects of the 1960/70s is identified.

TABLE 1
ASSUMED PROGRESSIONS IN A NUMBER OF 1960/70s SCHOOL SCIENCE CURRICULA

Curriculum	Progression
Intermediate Science Curriculum Study USA (Yrs 7 - 9)	The increasing complexity of relations between concepts in physics → chemistry → biology
Science – a Process Approach AAAS, USA, and Science 5-13 England (Primary)	A hierarchy of intellectual processes thought to be related to the methods of Science
A.S.E.P. Australia Yrs. 7-10	From learning via concrete experiences of Science to topics that involve abstract logical operations in their learning
Schools Council Integrated Science Project, England (Yrs 9-11)	From simple patterns (relationships) to more complex patterns in chemistry/physics/biology/earth science and in Science and Society
Nuffield "O" Level Chemistry England (Yrs 9-11)	From qualitative, practical engagement with chemical phenomena to mathematical and abstract atomic scale representation of them

The assumed progressions in Table 1 are not confined to its exemplary projects. They have existed, and indeed often still exist, in one country or another since their first appearance in the 1960s and early 1970s. Two of the progressions in Table 1 were very evident in the review of Queensland science curricula.

One other idea for science progression from this period, more than 25 years ago, was the list of 'conceptual schemes' by the National Science Teachers Association in the USA in 1964 (NSTA, 1964). Combined with Bruner's (1960) notion of a spiral of learning these "big ideas" of Science were to develop as they were visited and revisited by students and their teachers. Such progressive understanding was, alas, not evident in the evaluations in practice of two curriculum projects, PSSC and BSCS, that did take such "big ideas" seriously. Even the most enthusiastic supporters of the spiralling curriculum were thinking of months, a year or two at the most, as their time scale.

Each of the assumed progressions in the 1960/70s was derived from the nature of science or from the internal logic of the academic disciplines of science as they have developed, particularly conceptually since the mid 20th century.

In the 1980s, as the challenge of Science for All was taken up by a number of countries, a number of curriculum projects began to appear that had other assumptions about progression in science learning. These projects took seriously research findings about how students learn about natural phenomena (e.g. SCIENCE PLUS, Eastern Canada, Yrs 7-9), and about how the interactions between Science and Society can contribute to, and enhance the teaching and learning of school science (e.g. Salter's Chemistry and Science, England; and PLON, Physics, The Netherlands, both Yrs 9-11) (see Fensham, 1991). Each of these projects was developed with a very clear target audience of young people in mind whose lives outside school were important defining contexts for them as learners of Science. The Salter's authors expressed their curriculum approach by "starting with material and phenomena familiar to 13-16 year olds from their own experience, or from TV or books, and by introducing science concepts and explanations only when they are needed in working on these everyday things" (Smith, 1988).

THE ASSUMED PROGRESSIONS : DISCIPLINARY CONTENT KNOWLEDGE

The first versions of the National Curriculum for Science in England and Wales had the most elaborate structure which probably illustrates how progression was conceived most clearly. One of them had 17 designated *"attainment targets"* and 10 levels of learning in each. Of the 17 attainment targets 15 were effectively broad content areas of Science (such as **Processes of Life** and **Electricity and Magnetism**). Each of these attainment targets had a 10 level sequence of learnings. Although there was some recognition of the importance of applications of Science, the statements in the sequence of learnings were essentially related to developing in the learners knowledge and understanding of *Forces*, *Nature of energy*, *Variation and its genetic and environmental causes* or whatever broad science content area that was involved.

The complexity of a matrix of 170 cells for presenting school Science to teachers and students, not surprisingly, quickly led to a revised version with three content targets and one process one. Despite their slightly disguised titles, the content strands were now essentially chemistry, physics and biology.

The projects for national Science curricula in New Zealand and Australia were provided with matrix structures very similar to this later form of the one in England and Wales. In both New Zealand and Australia there were four aims of "subject" achievement (earth science was added) with another one *Making Sense of the Nature of Science and Technology* in New Zealand, and *Working Scientifically* in Australia.

The use in New Zealand of *"Making Sense of ...."* in the title of each of the achievement aims is an important recognition of research findings in science education, much of which has been contributed by the group at Waikato University over the last 14 years. It is sad to see that this implied constructivist emphasis is missing in the English and Australian counterpart documents, since similar research findings have also been found by scholars in these countries.

These sequences of content for learning thus stretch what was essentially an earlier form of secondary science content downwards across 10 years and what was a primary content emphasis, namely, processes of science, upwards across the whole period of compulsory schooling. It is as if the overt stages in ASEP have been combined with the more pragmatic form they took in the Nuffield "O" level sciences (see Table 1), but now spread over many years instead of over the 3 or 4 years these projects were for when they were first designed. The fifth strand is a latter-day version of the separation of process from content that existed in Science a Process Approach or in Science 5-13.

CURRICULUM OPPORTUNITY: MILITATING AGAINST PROGRESSION

I wish now to suggest another quite different approach to school Science that can be linked to the findings of the Discipline Review in 1988-9. The Report (Speedy,Fensham, Annice & West, 1989) of the Discipline Review was at its most pessimistic about science in primary schooling. After more than 20 years in Australia, innovation after innovation has been tried, involving every aspect and key player in the curriculum process. In none of the country's education systems was primary science found to be generally alive and well, and its presence in teacher education in most of the universities and CAEs was marginal at best.

The situation in lower secondary schooling was totally different. There was a significant and unquestioned place for Science in the timetable. There were specially trained teachers, and most of them had access to a technically supported laboratory for at least one or two periods per week. Although there was not a uniform sense of excitement, innovation and success about the science education in this sector of schooling, the secondary teachers were being prepared for, and many were teaching innovative thematic or modular curricula. There was little talk of serious constraints on what could be done.

On the other hand, constraint was very evident in the upper secondary years of science education as external assessment confined curriculum adventure to a minimum. However, at these levels there was the greatest concentration of human and physical resources for Science.

To make sense of these different potentials for Science in schooling, I have tentatively coined the term, "Curriculum Opportunity for Science Education" (COSE). On a 10 point scale of COSE, the primary years at present might rate 1 or 2, the lower secondary years would be 8-10, and upper secondary say 5 or 6. Early childhood education, although largely still ignoring Science at the time of the Review has, I suggest, a higher COSE than the primary years because of its traditions of social and practical experience and its dissociation from reading skills and hence from text book Science.

Given the vast gap that these situations revealed between the potential for Science in the primary school and lower secondary and the difference in constraints between lower and upper secondary, it seems that the steady progression implied in the national curricula is not how science learning can most effectively proceed through schooling.

PROGRESSION OF CHANGING PURPOSES

Just as COSE varies from sector to sector of schooling, so, I believe, does the purposes that science education can and should play. To ascertain whether there is some consensus among teachers about possible purposes, I have found it useful to use as curriculum purposes the seven curriculum emphases that Roberts (1982) found among science curricula in North America, and the two additional ones that relate to some more recent curricula (Fensham, 1994). With the constraint that only three of these can be major purposes in any one or two years of schooling, it seems likely that a high degree of congruence among groups of teachers could be found. Table 2 gives an indication of the purposes that are likely to have strong support for the four sectors for which COSE was discussed.

TABLE 2
CURRICULUM PURPOSES FOR SCIENCE IN THE LEVELS OF SCHOOLING

Level of Schooling	**Curriculum Values or Emphases**
Early Childhood	Everyday coping; Science for Making; Science for Nurturing
Primary	Everyday Coping; Science for Making; Science for Nurturing and/or Everyday Coping; Self as Explainer; Scientific Skill Development
Lower Secondary	Everyday Coping; Scientific Skill Development; Science, Technology Decisions; Self as Explainer; Correct Explanations
Upper Secondary	Solid Foundations; Correct Explanations and Structure of Science; Science, Technology, Decisions

The association in Table 2 of a purpose in say, the Early Childhood sector, and its non-appearance in later sectors does not, of course, mean that that purpose for science education has no place in later schooling. Rather, such a major purpose listed in Table 2 should be seen as being so emphasised in the sector where they do appear, that students will adopt this perspective and its related questions as part of their growing awareness for making sense of their learning of science. They would, in this approach, continue to expand this awareness, adding other purposes and their questions, as they proceed through the years of schooling.

This growing awareness of science and science learning is a very different type of progression from those suggested in the national curricula. If such a basis for progression were followed through, the next step would be to select content for learning that would enable students to become aware of these purposes. This content for learning (themes to explore, problems to solve, concepts for describing phenomena and for explaining questions about them) should, in turn, define the appropriate pedagogies, although the COSE factors and constraints will also come in strongly at this point. As the concepts usually associated with school science, and others that these sorts of content require for satisfactory resolution, are encountered in different contexts, so students' understanding of them can be expected to deepen.

I contend that the progressions, defined as the national projects have done from within science itself, are doomed to fail, as they have through the 1970s and 1980s as more and more students stayed on for 12 or 13 years of schooling.

In the 1990s, all students are now at school for the years of the national curriculum and the great majority will not become scientific professionals. All will, however, be citizens in societies in which science and technology permeate every aspect. As students move from age 4 or 5 when they begin their early childhood schooling to 16 or 17, the experiences they have of the world outside of school change considerably.

In harking back to the 1960/70s when the **Induction into Science** of a few was seen as the appropriate role for school science for the rest of this century and beyond the national curriculum planners have overlooked the 1980s when school science was increasingly seen as a means to **Empowerment from Science** rather than an end in itself. In fact, the approach I have just described - from purpose to content to pedagogy - is just what a number of sectorial science curriculum projects had begun to take in the 1980s in a number of countries (Fensham, 1991).

If we do want a science education that makes sense and optimally serves all students in schooling, then a variation in purpose for science in schooling such as Table 2 suggests is needed. If the purposes at different stages are clear, then the associated content for learning and pedagogies to make this possible will follow, and be very different from what the national curricula are suggesting.

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THE DEVELOPMENT OF A K-3 SCIENCE PROGRAM IN THE CONTEXT OF THE NATIONAL SCIENCE STATEMENT AND PROFILE

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ABSTRACT

This paper highlights the challenges and problems in developing an innovative K-3 science program to support teachers in the implementation of the national Statement and Profile in science. The program has been developed by the authors in association with the Curriculum Corporation. The paper outlines the assumptions made about teachers of young children, the role of research in the construction of the program, and the extent to which the Statement and Profile have influenced the process. The resolution of a number of key problems in this curriculum development is discussed: responding to teachers' needs for a base of science discipline knowledge, developing strategies for working scientifically with very young children, and helping teachers develop an extended understanding of the nature of science.

INTRODUCTION

In 1994 the National Curriculum Science Statement and Profile were released (through the Curriculum Corporation of Australia). Two years earlier, in 1992, there had been a recognition by the Curriculum Corporation that early childhood and primary teachers would need to have access to support materials which would assist them implement these new developments. As a result, the Curriculum Corporation during 1992 set up a national Science Curriculum and Teaching Program which included the plan to develop a K-3 Science Program. A program of 18 units with different content foci and teaching approaches was planned. The authors directed this program from 1992-1994 and it was developed together with early childhood teachers working in childcare centres, preschools and primary classrooms (K-3) throughout Australia. The ideas embedded in the program have been tried out with children in these settings, have been modified as a result of that trial, and the program is to be published by early 1995 (Fleer, Hardy, Baron & Malcolm, in press).

This paper highlights the challenges and problems in developing the program. We focus our discussion on the influences and links between a number of key features of the context for the curriculum development: the developers' assumptions and theoretical framework; research on young children's understandings in science; and influences of continuing development of the national Science Statement and Profile. To a lesser degree market forces were seen to have an impact on the program.

The relative influence of each of these factors is of special significance in understanding the final form which the program assumed. Such influence was partly dependent on the importance accorded to each of the factors, but it was also dependent on the adequacy or potency of the factor. In the case of the influence of existing research in science education, we accorded this major importance and the general constructivist research literature strongly influenced the initial conceptualisation of the project and provided the theoretical basis of the program. However, the influence of research on the development of the program was limited by the lack of research into very young children's scientific understandings (eight years and younger) in a wide range of relevant areas. It meant that the generalised understandings of learning and teaching of a constructivist approach became an essential guide in the project's planning and implementation in classrooms. Within the limited time available, we also incorporated a significant research component into this curriculum development project.

THE UNDERLYING ASSUMPTIONS OF THE PROGRAM

Throughout the process of developing this program, a number of important assumptions about early childhood practice informed its construction. These assumptions, some of which were influenced by the general science education research literature (e.g. Biddulph & Osborne, 1984; Osborne & Freyberg, 1985), provided the framework for the initial conceptualisation and final realisation of the program. Key assumptions are discussed below.

Pedagogical knowledge

Teachers' existing understandings and skills in teaching are typically of a high order, and the science program was developed to build on this expertise. Although it was expected that teachers may not have had many experiences in teaching science (Department of Employment, Education and Training, 1989), they generally would have in many other curriculum areas well developed classroom management skills, such as the organisation of cooperative learning, small and large group activities, and high student involvement both metacognitively and with hands-on resources (NBEET, 1992). It was considered that since teachers already possessed the pedagogical skills needed to teach science effectively, more program space would be devoted to the telling of "stories" by each teacher in each unit - what science looked like in their centre or classroom. The pedagogical details could be easily inferred from the story as well as allowing teachers to take the story and re-develop it to suit their children's needs. In addition, learning outcomes could easily be inferred from the children's work samples scattered throughout each unit. Consequently each unit was not a sequence of activities, but rather a picture of what science could look like in a particular science content area.

Teacher knowledge of science

An effective teacher of science will have an appropriate base of science knowledge for a particular topic being taught. It was an assumption of the project that a teacher should also have a good basic understanding of the nature of science and about what it means to work in a scientific way. Such a general understanding should assist a teacher to contextualise a science topic, to respond more effectively to children's contributions and to develop a general sense of competence in teaching science.

Holistic view of learning and teaching

Early childhood teachers traditionally focus on holistic learning and teaching in both their planning and implementation. This was a strength of the cohort of teachers who were involved in the development and teaching of units. The natural inclination of the teachers was not to view science as a separate area, but rather as a part of the whole teaching program (NBEET, 1992). Consequently, the program highlights science within the context of the whole curriculum and whole child's development - social, emotional, physical as well as cognitive.

The 4-8 age span

Early childhood teachers have a sound understanding of the range of developmental needs of children aged 4-8 years. Within this age band a variety of reading, writing, physical, social and language skills are evident, all influencing how learning can be structured. The final

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format of the program encompasses this variability through direct references to examples of children's work across the age band, and examples of learning contexts for both four and eight year olds. The assumption here is that a Preschool and a Year Two teacher can both identify the relevant aspects of each unit in the program for their children and recognise the learning outcomes inherent in each unit.

Different learning environments

In the K-3 area there is a range of learning contexts - preschool, school and childcare. Each learning environment has its own characteristic features, including its constraints. Consequently, an awareness of the different physical and organisational learning environments in early childhood needed to be evident within the program.

Family involvement

An important element within early childhood education is the involvement of the family, and this was demonstrated in the program through a number of units. Specific follow-up home based experiences to link and support learning in the school/ centre featured, for example children being involved in cooking at home or looking for condensation in the kitchen or bathroom featured.

Home-school links were also a crucial element in the unit on night and day, Night is a Big Shadow. It was essential that the children made observations of the night sky, and hence family participation was seen as both necessary and highly desirable with opportunities for very worthwhile child-adult interactions. A booklet, My Night and Day Book, was produced for each child in which they were asked to draw what they saw and to write what they felt (parents were requested to scribe for younger children). Given our plans to teach this unit so that children gradually developed understanding that the rhythm of night and day is related to the spin of the earth, we did not want parents to didactically tell the children this early in the unit. In the covering letter to parents and in the introduction to the booklet we sensitively provided guidance, asking them to listen and help their children report what they saw and felt.

The effect of family involvement on children's learning was also researched. This element of the study was reported in Fleer and Hardy (1993).

Context

A sense of purpose for children in learning was a key element in framing each unit and was conceptualised at the commencement of the project. Each unit begins by describing a context of learning which is meaningful for children, and establishes a sense of purpose for the child and a way of motivating the child to become engaged with the unit. For example, in looking at natural and processed materials, the context is created through the story telling of "Are you my Mother" by P.D. Eastman but with real kitchen utensils and simulated cupboards (from boxes). This puppet story telling sets up a context to talk about materials with the children. It also allows children to draw upon their home based experiences, since the props are familiar to them and relevant to their lives.

Fensham (1994) has suggested that the basis for progression in learning from early childhood to secondary, should in the early years begin with young children's interests, needs and purposes and progress to correct explanations and structures of science. In particular Fensham outlines three purposes for early childhood science education: Everyday coping; Science for Making; and Science for Nurturing (p. 6). These values or emphases expressed by Fensham are consistent with the focus of the K-3 program, since the context created for each unit embodies these.

We have been mindful as we have developed the units that they would be utilised throughout Australia with its diversity of location, geography and communities of people. The program needed to be readily adaptable to any situation, for instance whether it be urban or rural, and for Aboriginal communities. There has been sensitivity in the construction of the program to the perspectives and activities of both girls and boys and to children from different ethnic backgrounds. In some units, there are suggestions about how to enrich the learning experiences of all children by including gender or ethnic perspectives. For instance in the unit, Movement in the Toybox, dealing with energy in moving toys, it was suggested that toys be included from children whose families have emigrated to Australia.

Teachers constructing their own program

The program needed to ensure that it reflected the different styles of teaching and of reporting. The necessity for this assumption was evident in the diversity among the teachers who developed the units for this program. Not only do the different styles reflect different philosophies and preferences among the teachers, but the different children and locations in which the science was being taught. We thought this would allow teachers using the developed program to identify closely with some units and to reshape other units to suit their own situation and style of teaching.

Teachers need to construct their own program in science in order to have ownership and for it to be relevant and useful for the children in their class/centre. Teachers have the general curriculum expertise to adapt units in the science program and to construct their own units. Some of the units that were developed for the K-3 program are more detailed in terms of what the children know about the topic, the questions they were interested in and what took place in the classroom. Other units merely hint at these areas. It is expected that teachers will, in the first instance, follow the units more closely especially in traditionally more difficult content areas of science. In areas where teachers feel more confident they would select and choose from the available ideas to suit their own curriculum needs.

INFLUENCE OF THE SCIENCE STATEMENT AND PROFILE

This program was primarily developed to support teachers of young children in their implementation of a science program that was informed by the Australian Science Statement and Profile. While it was necessary to be sensitive to these documents, there was a commitment to incorporating features that we considered were essential, whether they were, or were not to be found in the documents. We were supportive of the general thrusts of the national documents, with their emphasis on a constructivist approach to learning, their concern about principles of equity, particularly with respect to the education of girls, and their encouragement of creating links in teaching and learning across the five strands. The Profile was still in draft form as the project began and was undergoing trialing and revision during most of the course of the project. The Profile appeared to hold promise for more effective teaching and learning though its vigorous advocacy of an outcomes approach.

In reflecting back on key decisions in the project over the past two years, it is of interest to ascertain where our own assumptions and approaches were compatible with the new directions of the national curriculum and where tensions existed. Key influences of the Science Statement and Profile on curriculum decisions are explored in the following.

Initial influence of the Science Statement and Profile

Our brief was to develop a program, which if followed as a whole by a teacher, could be seen to encompass all of the five Strands and which would provide suitable learning contexts for children especially in terms of outcome Levels 1 and 2 (and to some extent Level 3). To ensure comprehensiveness we used the outline of the Strands as a grid to check on ideas that we had developed as possible topics. Some of these had emerged from research that we had been doing (see below for details) and from work completed by teachers in the PECSTEP inservice program (Hardy, Kirkwood & Bearlin, 1990). The remaining units were suggested to us by the Strand framework. At an early stage, the project's Reference Group, who provided advice to the team, pointed out that the list of intended contents neglected scientific processes. The project team then realised that naming all of the intended units by content themes had given that impression, although it was planned that all of the units would incorporate elements of working in a scientific manner. However, at a later stage of the program's development, it was decided to have as a capstone unit, one that had been explicitly focussed on the Working Scientifically strand (and the rationale for this is discussed below).

Cliff Malcolm, coordinator of the Science Curriculum and Teaching Program advised us initially that the program was not to be driven by the Science Profile (which would have very difficult even if this had been considered desirable, given that they were still being finalised). Rather we should be aware of the Profile, and use it as a loose guide in development work. Towards the completion of the project, decisions would need to be made about how closely aligned units would be to the Level statements of the Profile.

We followed this advice. Teachers did not systematically make use of the Profile during the developmental stages, although some made reference to the document during their teaching. One outcome of the project was that there did not appear to be any glaring incongruities between the Profile level statements and the levels of learning outcomes that were achieved by children in the groups which were developing and trialing the units.

Reporting the learning and teaching experiences

As already noted, it was planned that the program would be in the form of teacher stories. The challenge was to write these so that the richness and complexity of the learning and teaching could be captured, and experienced teachers would make sense of the story and redevelop it for their own contexts and children. We perceived that the Science Statement and Profile encouraged teachers to see effective teaching and learning of science as being multi-faceted and contextualised, and hence encouraging of the portrayal that had been planned.

The reality of interactive teaching is its unpredictability and often divergent course, and this was evidenced in many of the units of the project. While it was difficult to capture this complexity in the written form, early drafts of units did portray this. But the units had to be written in an accessible and inviting manner so that teachers would be encouraged to attempt the topics and approaches discussed. Later drafts became more focussed and sequenced in an apparently more logical sequence of activities: as a consequence some of the richness and complexity was lost. While this was not what we desired, it probably meant that the units became more accessible for a wider range of teachers.

Final stages and the influence of the Science Profile

By the time that the program development work in the field was complete at the end of 1993, the Profile had reached its final edited version. Early in 1994, a draft of the program was sent out for comment across the States and Territories. It was clear by then that education departments were committed to using the Profile, either as it was to be published or in some modified form. Not surprisingly, some of the feedback on the draft from departments suggested that there was a need to tie the units more closely to the Profile if the program was going to be widely adopted and utilised. One of the consequences of this market force was that all of the units were eventually introduced with explicit reference to relevant sections of the Profile. The language of the units became more in tune with a learning outcomes orientation in teaching, and this meant there was a reduction in the strength of the voice of the individual teachers and the children.

On reflection, these influences now seem inevitable given the new context for curriculum development posed by the national collaborative curriculum work in science (and other key learning areas) and by the need for resources marketed by the Curriculum Corporation to be financially successful. The modifications in the final stages of development were a reasonable compromise: the key intentions of the project permeated the units and the program as a whole. Fensham (1994) has recently expressed concern over some aspects of the national curriculum developments, commenting particularly upon the progression inherent in the science curriculum statement and profile. While sharing some of these concerns with Fensham, we believe that his fears about the potentially damaging effects of the Science Profile are not to be found in this early childhood program.

THE RELATIONSHIP OF RESEARCH TO PROGRAM DEVELOPMENT

The project drew upon previous research conducted into early childhood aged children's understandings in light (Fleer & Leslie, 1992; Segal & Cosgrove, 1993), the life cycle (Baron & Gray, 1993), the human body (Fleer, 1994a) and electricity (Fleer, 1994b) to inform further research and the curriculum development. However very little research into 4 to 8 year olds' understandings in science could be located in the literature: most research focused on children above the age of ten years. Consequently, the data collected as part of the curriculum development was very important for guiding the development of the program was a whole.

The development of the units involved "new territory" and children were interviewed prior to the commencement of the teaching program. As a result, some basic research was carried out with groups of children, not only to guide the development of some of the units, but as a way of finding out about very young children's thinking in areas unexplored by research. The areas that were systematically investigated were night and day, natural and processed materials, and living and non-living. In each case a pre and post interview was conducted to find out what children thought about the concepts in the areas detailed above.

As with previous research in science with young children, creative ways needed to be developed in order to find out what children think - for example tracing around children's bodies and encouraging children to draw their internal features (Fleer, 1994a); creating a darkroom for children to explore with torches and other lights (Fleer & Leslie, 1992). We decided that showing young children a range of drawn pictures such as in the interview-about-instance, commonly used to elicit older children's understandings (Osborne & Freyberg, 1985), was deemed inappropriate for such young children.

In the case of natural and processed materials, the context for interviewing was created through puppets (water), an interactive story book which featured several white board pages for collecting ideas (liquid, solid and gas) and children viewing video segments of a number of events such as putting on sun screen or rotting food (chemical change) (Fleer & Hardy, 1993).

With regard to night and day, the existing research focussed heavily on older children, but it was very helpful in underlining the need to focus tightly on a topic. For instance, Baxter (1989) showed that among adolescents there was significant variation in their explanation for familiar astronomical events. We decided that given the potential for confusion as an outcome of teaching about motions of the earth, moon and other planets, we would develop the unit with one primary focus: assisting children to develop an understanding of the relationship of the spin of the earth and night and day. This decision was also supported by the interviews that we carried out with children at the preschool and Year 3 level, where again confusion about astronomical motions was evident. These interviews extended the work of Klein (1982) with Grade 2 children and made use of models. Questions about night and day were set within the context of a specially written story about a child's birthday to which children could readily relate.

The research and teaching were mutually beneficial since the research informed the teaching and the teaching informed the research. The teaching approach used for most of the units was predominantly the interactive approach to teaching science (Biddulph & Osborne, 1994), and it was relatively easy to build a research component into many of the units developed for the program. The units as reported constitute case studies which include summaries of children's questions, understandings, and in some cases, transcripts of teacher-child discourses. For example, individual and group concept maps were collected as a way of providing information to the teacher regarding what young children already know about a topic and the range of weird and wonderful alternative views likely to be held. Similarly, individual and group concept maps provided useful base data on young children's thinking across a broad range of science topics. However, due to time constraints on the part of the researchers it was not always possible to interview all the young children involved in each unit. Although the group concept maps provided some general data on the ideas held by very young children about a range of science concepts, it was not regarded as a sufficient sample from which to make any generalisations. Where research was already available into older children's understandings, it was possible for some group data comparison.

The development of the program clearly underlined the need for much more research into very young children's understandings of science.

MAJOR CHALLENGES IN TEACHER DEVELOPMENT

As has been noted earlier, one of the project's fundamental assumptions was that the teachers of young children are well-qualified and often have a wide range of expertise and knowledge in education. One of the most important messages that we tried to make transparent in all the units was that teachers could use the whole range of their teaching skills in the program: teaching science is no different in many respects than, say, the teaching of language or mathematics. With this realisation, we hoped that any teacher could readily incorporate science into other learning activities for children, thereby enriching and extending their learning experiences.

But at the outset of the project it was recognised that some early childhood teachers do not accord the teaching of science a high priority and it may not constitute a substantial part of their overall curriculum. Such teachers are likely to have doubts about the teaching of science, and as a consequence the scientific aspects of the units were emphasised in the program. It was a key goal of the program to develop:

- teachers' base of science discipline knowledge;
- strategies for teachers in working scientifically with young children; and
- teachers' understandings of the nature of science.

There is ample research that indicates that teachers' confidence and sense of competence is related to their view of the adequacy of their knowledge about science (see for instance, Appleton, 1993, pp. 32-34). This was confirmed during the project when some of the teachers trying out the units requested more assistance with developing an adequate knowledge base.

The challenge was to assist teachers to overcome this view of their inadequacy in supportive, non-threatening and "clever ways". Given that there was no certainty of a professional development course to accompany the K-3 program, the achievement of such change had to be attempted through the written program.

Science discipline knowledge

A number of approaches were used to address this problem. One was to list some resources which teachers could consult to extend their understandings in specific areas of science. In some units, teachers were provided with a table of research findings on children's views of scientific concepts contrasted with scientists' views. The dominant approach was to weave scientific concepts and information through the text as the stories of what occurred in the interactions of teachers and children were told. This allowed us to report to teachers "alternative" children's views, some of which teachers might share. It was therefore possible to explain obliquely to such teachers why their view was not a scientific view. For instance, in the unit Night is a Big Shadow we presented three different models which the children developed to explain night and how a teacher dealt with these competing views. Not only was an appropriate pedagogy suggested, but scientific content was being introduced and refined for teachers.

Working scientifically and the nature of science

Each unit of the program incorporated elements of the Working Scientifically strand, and a teacher following the program should develop their expertise and understanding of this strand. As noted above, it was decided that a unit should be developed which was more explicit about the strand and at the same time would emphasise key features of the nature of science. It was decided that such a unit would best be placed at the end of the program, so that a teacher would consolidate learnings from earlier units.

This unit is the last chapter in the book, *They Don't Tell the Truth about the Wind: A Unit about Working Scientifically*. It is a unit where the topic content (the weather) takes second place to the emphasis on the processes and epistemology of science. The chapter was consciously written as an opportunity for a teacher to look over the shoulder of the teachers developing the unit as they make critical decisions. For instance, at an early stage one of the teachers shares his concept map of what it means for him to work scientifically, encouraging the reader to also develop such a map. This unit, therefore, also serves the explicit function of supporting teachers to plan and develop their own units in a science program.

The unit outlines what decisions were made before teaching commenced, how teachers prepared, what teachers did in the classroom and what children learned. But in contrast to earlier chapters, this unit extracted from the text key summary statements which were placed in sharp relief in boxes. For instance, the unit summarises the work of children in reporting and describing their observation of clouds. These were represented in an artistic manner through the use of cotton wool and a painted sky background and through the children comparing them to animal and other shapes. The text then makes the point that "People who are effective in working scientifically use their imagination in making sense of their work and their world. Using metaphors is a common mode of understanding in science."

This section of the unit, as do others, therefore simultaneously suggests ways which the teacher can adopt in working scientifically with children, reinforces the teacher's developing understandings of the ways scientists operate and extends their understandings of the nature of science. The answer as to whether the program has succeeded in addressing teachers' expressed needs in these crucial areas will have to await feedback from the teachers who utilise the program over the next few years.

CONCLUSION

The K-3 Science Program has been developed to support the implementation by early childhood teachers of ideas embodied in the new national Science Statement and Profile. The shape and orientation of program has been heavily influenced by the developers' assumptions about the practices and generally high level of expertise of early childhood educators. The science education research literature has provided a general framework for the development of the program in the form of a constructivist learning and teaching approach. The lack of research into young children's understandings in many of the areas of learning which had been chosen for this program was partly overcome by incorporating some basic research before and during the curriculum development process. However, for some sections of the work it was general understandings of children's thinking and learning that was the predominant guide in their development. The influence of the Science Statement and Profile was helpful in ensuring a comprehensive range of themes and topics and supporting the pedagogical approaches adopted. While market forces inevitably influenced the final stages of the program development, it is argued that the integrity of the program as a significant contribution to early childhood science education has been maintained. Confirmation that this will be the case awaits future research.

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NEWTON'S THIRD LAW AFTER NEWTON

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ABSTRACT

Newton's third law is not something which students easily accept. This is largely due to the widespread notion that the force exerted by a moving body is directly related to the speed or to the mass of the body (or to both) and not to the nature of any interaction in which that body might be involved. The aim of the paper is to identify some of the issues upon which debate took place over the phenomenon of impact in the early 18th Century. This is achieved by studying a number of the popular textbooks and commentaries on mechanics which were published at that time. Some implications for teaching Newtonian mechanics are outlined.

INTRODUCTION

In a previous paper (Gauld, 1993) the historical context of Newton's third law of motion was discussed taking as a starting point those writers such as Wren, Wallis and Huygens to whom Newton gave credit for establishing the truth of the third law. This context highlights the crucial role played by studies of impact around the middle of the 17th century in providing what Newton claimed was a firm empirical foundation for this "axiom of motion".

However, in addition to informing us of the context from which such an important principle emerged, history also allows us to explore the way in which this principle was assimilated into the thinking of the scientific and non-scientific community. For teachers of science this has particular relevance since the ideas with which Newton's third law had to contend then may be much the same as those students possess now.

This paper deals with some aspects of this assimilation by investigating the treatment of impact phenomena in a number of popular presentations of "natural philosophy" written in the early 18th century and used extensively in England. The first Latin edition of Newton's Principia Mathematica was published in 1687 and, before the first English translation of this work was published in 1729 (Newton, 1729/1960), there were many attempts to present Newton's ideas to a wider English audience than those working in the field of natural philosophy.

John Keill, Savillian professor of Astronomy at Oxford, wrote in 1701, the first Latin Newtonian physics textbook (Gjertsen, 1986, p.284) which was followed by an English translation in 1720. William Whiston's Sir Isaac Newton's Mathematick Philosophy More Easily Demonstrated was the written version of "forty lectures read in the publick schools of Cambridge" and published in 1716. Wilhelm Jacob 'sGravesande (professor of mathematics and philosophy at the University of Leyden) published in 1720 a Latin textbook, Physices Elementa Mathematica, Experimentis Confirmata: sive Introductio ad Philosophiam Newtoniam which was translated into English by John Keill in 1720 and by James Desaguliers in 1721. John Clarke's English translation of the textbook, Traité de Physique, written by the Cartesian Jacques Rohault (first French edition 1671) was published in 1723 with extensive Newtonian footnotes by his brother Samuel Clarke (Hoskin, 1962). Henry Pemberton published his defence of the Newtonian philosophy in 1728.

The English translation of the Principia was not easy reading for the ordinary person and other books, written to assist the general public understand its ideas, continued to appear after 1729. Richard Helsham's A Course of Lectures in Natural Philosophy appeared in 1739 and in 1751 Benjamin Martin published A Plain and Familiar Introduction to the Newtonian Philosophy which was "designed for the use of such gentlemen and ladies as would acquire a competent knowledge of this science, without mathematical learning". Books, widely read in Europe, were translated into English to assist in this task. A popular book by Francesco Algarotti first published in Italian in 1737 was translated into English by Elizabeth Carter under the title Sir Isaac Newton's Philosophy Explained for the Use of Ladies. It ran into at least five English editions between 1739 and 1772 (Gjertsen, 1986, p.14).

Three books, representing the major positions with respect to the phenomenon of impact in the early 18th century, will now be discussed in more detail. These are Whiston's book and Clarke's English translation of Rohault's textbook both referred to above and the English translation of a series of lectures by 'sGravesande translated by Edmund Stone in 1741 under the title An Explanation of the Newtonian Philosophy in Lectures Read to the Youth of the University of Leyden.

WHISTON'S "SIR ISAAC NEWTON'S MATHEMATICK PHILOSOPHY"

William Whiston was Newton's successor as the Lucasian professor of mathematics at Cambridge and was appointed in 1701. His book, Sir Isaac Newton's Mathematick Philosophy More Easily Demonstrated, published in 1716, "was one of the first works designed to present, in English, Newtonian physics in a popular form" (Gjertsen, 1986, p.610). Whiston explained how what we now call "inertia" gave rise to forces of impulse and resistance by amplifying Newton's concept of the "innate force of matter" (which Whiston called the "Force of Inactivity") as follows:

> a Body exerciseth this Force only when it is acted upon by some Force from without; under which exercise of its Innate Force it is considered in a Double Respect; to wit, as Resistance and Impulse. Resistance, as far as it struggles with the impressed Force, in order to preserve its own State; Impulse, as the same Body by not easily giving way to the Force of the resisting Obstacle, endeavours to change its State. Indeed, it seems most proper to attribute Resistance to quiescent, and Impulse to moving Bodies; and I should assign any Impetus whatsoever, where one of the Bodies is at Rest, to the positive Force of the moved Body, rather than to the Negative Force of the quiescent one (pp.41-42).

His statement of Newton's third law was a little more compact than Newton's and referred to both impulse and attraction, that is, to contact forces and non-contact forces.

> Re-action is always contrary and equal to Action. That is, the Actions of Two Bodies acting upon each other, whether they be Impulses or Attractions, are always directed each to the contrary Part, and are also equal (p.48).

Oddly enough, in his discussion of the collisions of inelastic bodies Whiston made no reference to the third law of motion even though his treatment of such collisions followed immediately on his extensive treatment of this law.

For a collision between two equal, inelastic bodies, one moving and one at rest, he argued that during collision, as long as the velocity of the initially moving body was greater than that of the initially stationary one, the former would accelerate the latter. When their velocities were equal this acceleration would cease (p.51).

For two unequal, inelastic bodies which move towards each other with equal speeds he used language reminiscent of the impetus theorists.

> The Quantity of Motion in both, taken together after the collision will be the difference only of the former Motions; for the lesser Quantity of Motion on either Part will be equivalent to an equal Quantity of Motion on the other Part, and as above will destroy it; wherefore, there remains only the Excess of the Motion, as the sole Cause of it after the Shock (p.52).

Whiston pointed out that these laws of collision apply equally to inelastic bodies (bodies which deform but have no tendency to restore themselves) and to perfectly hard bodies (those which do not deform at all). On the other hand he claimed that the laws for perfectly elastic bodies (that is, bodies "which restore themselves with the same Force wherewith they are compress'd") needed to be presented separately because they were completely different from those for inelastic bodies (p.54).

Again, for elastic collisions, there is no appeal to the third law of motion. Instead, Whiston treated the first part of the collision between two equal, elastic bodies, one moving and one at rest, as he did for inelastic bodies. At the end of this process the two bodies move together with half the speed of the initially moving body. However, elastic forces now take over.

> By its Elasticity, the Force of which is equal to the Force of the direct Impulse, [the impelling Body] will communicate the other half of its Motion, from whence it came, that the Motion of the Body before quiescent, will now be equal to that which the Impellant had before; and consequently, that seeing so much of Motion as the Impellant transfers to the other, so much it loseth of its own Motion, the Motion upon the whole will be convey'd into the Quiescent, the Impellant having lost its Motion (pp.54-55).

Whiston's treatment displays a less than elegant or consistent presentation of the Newtonian position and perpetuates some of the ambiguities which still remain in the Principia (see Gauld, 1993).

"ROHAULT'S SYSTEM OF NATURAL PHILOSOPHY"

Traité de Physique by Jacques Rohault first appeared in 1671 sixteen years before Newton published his Principia. The Latin translation (with Newtonian footnotes) by Samuel Clarke in 1697 was used as a textbook in Cambridge during Newton's professorship there (Shea, 1988) and an English translation was produced by Clarke's brother in 1723. The book was still being used in 1735 in England and 1743 in America (Sarton, 1948). Rohault was a follower of Descartes and the book presented a comprehensive coverage of motion, light, astronomy, geology, meteorology and animal biology.

Some distinctives of the Cartesian position which were presented in Rohault's book included the following:

- God created the world with a fixed Quantity of Motion (mass x speed) none of which was lost during impact (Rohault, 1723, Vol.1, p.46).
- Motion was transferred through impact. Attraction (action at a distance) was rejected as an occult quality "and therefore ought not be used in the better sort of Natural Philosophy" (Vol.1, p.54).

- The motion of the planets around the sun could best be explained by the action of vortices in the subtle matter which filled the space occupied by the solar system (Vol. 2, p.66).

Descartes had enunciated a number of laws of impact some of which even his staunchest supporters had to admit were faulty. For example, he claimed that

> If C is at rest and is slightly larger than B, then no matter how fast B is moved toward C, it will never move C but will be repelled by C in the opposite direction. For a body at rest gives more resistance to a larger velocity than to a smaller one in proportion to the excess of the one velocity over the other. Therefore it is always a greater force in C to resist than in B to impel (Blackwell, 1966).

In Rohault's treatment of impact, Descartes' position was presented in such a way that it did accord with experience. For Rohault, from the principle of the conservation of the Quantity of Motion,

> it follows, that if a Body in Motion, strikes directly upon another Body at Rest, and pushes it before it, it must necessarily lose as much of its own Motion, as it communicates to the other, in order for them to go on together with the same Celerity as if the two Bodies were one common Mass.... If a Body in Motion, strikes upon another Body in Motion also, it will make that move swifter; but it will not lose so much of its own Motion, as if this latter had been wholly at rest; because all that it has to do, is only to add some Degrees of Motion to those it has already, in order to make the Bodies move with the same Celerity (p.48).
>
> If a Body in Motion strikes upon another, which it cannot move at all, we ought to conclude, that it will continue to move on with the same Celerity as it did before; but because the Body which it cannot move, hinders its Determination, it must necessarily alter this Determination, that is, it will be reflected (p.81).

Rohault thus chose those situations which could be understood using Descartes' principle of conservation but ignored those cases (such as bodies moving towards each other or elastic collisions) where the principle cannot always be applied.

Samuel Clarke's footnotes were used to point out in no uncertain terms where he believed Rohault was wrong. For example, Rohault, appealing to Descartes' principle of conservation, stated that there could be no moment of rest when one body reflected off another. Clarke commented

> But it is not so....There may be a Moment of Rest, in the Point of Reflexion; because the reflected Motion, is not a Continuation of the Direct, but a new Motion impressed by a new Force, viz. the Force of Elasticity (Rohault, 1723, p.81).

In another footnote Clarke presented an elegant and comprehensive analysis of both inelastic and elastic collisions (Rohault, 1723, pp.49-52). It is interesting to note that the analysis he used followed the kinematic discussion presented by Wren, Wallis and Huygens to the Royal Society and made little reference to forces. The analysis involved two steps. In the first, an inelastic collision was presumed in which the total motion (taken algebraically with regard to direction) was the same before and after the collision. Thus the speed of both bodies after the collision was

$$V = (M_1V_1 + M_2V_2)/(M_1 + M_2).$$

If the collision were elastic this represented only the first part of the process. At this stage an elastic force existed which was directly related to the loss of motion of the initially faster body. When this elastic force acted to restore the shape of the bodies the same amount of motion had again to be subtracted from the initially faster body and added to the other body.

At the end of his mathematical solution to the problem of elastic collisions, Clarke gave a reference to Problem 12 in Newton's lectures on algebra at Cambridge between 1673 and 1683. In this problem Newton presented a concise analysis of elastic collisions which was based on two premises, namely,

> that each body shall suffer as much in reaction as it impresses in its action upon the other; and that after recoil they shall depart from each other with the same speed as before they approached (Whiteside, 1972, p.149).

This was quite a different treatment from Clarke's and it also differed from that approach in that it made explicit reference to the law of action and reaction.

'sGRAVESANDE'S "AN EXPLANATION OF THE NEWTONIAN PHILOSOPHY"

Wilhelm Jacob 'sGravesande was appointed to the chair of mathematics and philosophy at Leyden in 1717 and has been described as "the earliest influential exponent of Newtonian philosophy on continental Europe" (quoted in Gjertsen, 1986, p.235). The first edition of his Introductio ad Newtoniam Philosophiam was thoroughly Newtonian in flavour and was immediately translated twice into English ('sGravesande, 1720, 1721). However, by the time of the second edition of the popular version of that work ('sGravesande, 1741), the author had undergone a change of heart and in the Preface of this version he warned that

> though I have not follow'd the Opinion of Sir Isaac Newton in everything; and notwithstanding there are many Inventions of other Persons contain'd in this our Treatise; yet I have not scrupled to call it the Newtonian Philosophy.

One notable example of where 'sGravesande differed from Newton is provided by the comment which followed his statement of Newton's first law. He wrote

> A Body may move by its Force of activity, or active Power, and this Force (as follows from the Law but now mention'd) will not be changed, but by the Action of some external Cause (p.41).

'sGravesande was influenced by Leibniz's ideas about force. Leibniz believed that God created the world with a constant quantity of living or active force (vis viva) so that this force was conserved in collisions between bodies. He was convinced that Descartes was wrong because (mass x speed) as a measure of force was only sometimes conserved and, more often than not, the total of this measure decreased as a result of collisions. A more appealing measure of force for Leibniz was the scalar quantity mv^2 which had been shown by Huygens to be conserved in elastic collisions (Gauld, 1993). For Leibniz, forces were measured by their effects and he argued in many places that an object thrown upwards by bodies with the same value of mv^2 would reach the same height (Leibniz, 1686/1969a, 1692/1973, 1695/1969b). Although force appeared to be lost in inelastic collisions Leibniz claimed that it was conserved among the various parts of the colliding bodies (Weiner, 1951, p.271).

The details of Leibniz's mechanics were developed by 'sGravesande when he argued, for example, that "a Body resists Acceleration in the Ratio of its Velocity" ('sGravesande, 1741, p.74), that "Gravity, which communicates equal degrees of Velocity to a Body in Equal Times does not communicate equal Degrees of Force to the same" (p.76), and that "Forces are equal, if the Squares of the Velocities be inversely as the Quantities of Matter" (p.76).

'sGravesande's statement of Newton's third law of motion was unexceptionable and, unlike the Cartesians, he was quite happy to discuss attractions and to argue that Newton's third law applied to them (pp.44-45). He commented further that "all action requires Resistance; take away the one, and the other vanishes; for who can conceive an Action without an Obstacle?" (p.43).

His initial discussion about Newton's third law referred to situations which did not involve impact between bodies, and so, did not involve bodies acting on the basis of their vis viva. However, when later considering impact phenomena the situation changed. For example, 'sGravesande believed that, when two unequal bodies moving in opposite directions met "there arise two Actions, and two Re-actions, each Action being equal to its Reaction" (p.86). In other words, the two unequal living forces (mv^2) in the bodies gave rise to reactions which were equal to their respective actions but which were not equal to each other.

TRANSFORMATION OF DYNAMICAL CONCEPTS IN THE 17TH AND 18TH CENTURIES

During the 17th and 18th centuries there was a gradual change in the central ideas which were used to understand impact phenomena. The beginning of this period was dominated by a notion of force as the Impetus of a moving body (identified with the product mass x speed) while at the end force was something which was produced by the interaction of one body with another and generally resulted in a change in momentum (mv) and a change in "energy" (mv^2) for each body (see Young, 1807, pp.78-79). The transformation was dominated by debates about the nature of bodies, the nature of force and the way in which bodies in motion interacted.

Bodies could be hard and unyielding, soft and yielding but unable to restore themselves, or elastic in which case the original shape could be restored after deformation. Extension was the essential attribute of matter for some while impenetrability and inertia were of central significance for others.

Forces were believed by some to be both the cause of motion and of its continuation. For some there was a force of rest while for others the resistance offered by a body at rest was simply a result of its inertness or its impenetrability (Gaukroger, 1982; Gabbey, 1980). Bodies which were not in direct contact could affect each other either through a ubiquitous, subtle, fluid or by attraction, the nature of which was rather a mystery.

When two moving bodies interacted conservation of some property of the bodies occupied a central place in schemes of explanation but there were differences in what was believed to be conserved. For the Cartesian it was mv (taken as a scalar), for the Leibnizian it was mv^2, and for the Newtonian it was mv (taken as a vector).

The Leibnizian challenge to the Cartesians (Leibniz, 1686/1969a) about the appropriate measure of the force of motion should have been totally irrelevant for English Newtonians. They placed great emphasis on the passivity or inertness of matter (Helsham, 1739, p.50) rather than ascribing to it internal powers as did the Cartesians and the Leibnizians. In spite of this, many of these Newtonians sided with the Cartesians in the subsequent debate (Hankins, 1965; Iltis, 1971; 1973a). Papineau (1977) claimed that the power of the context of collisions brought to the surface concepts of the force of moving bodies which were of less relevance in the context of planetary dynamics. Even Newtonians were unable to resist the still present pull of older notions of impetus when the impact of moving bodies was the object of investigation.

Another indication that many Newtonians were less than thoroughgoing in their application of Newtonian principles can be seen in their presentation of solutions to the problem of impact. Instead of being as explicit as Newton was in using the third law when determining the behaviour of bodies after collision, use of a modification of the kinematic approach employed by Wren, Wallis and Huygens (see Gauld, 1993), in which conservation of motion was the major element , was widespread.

The central transformations over this period are summarised in Fig. 1 which shows that one view did not replace another in a linear progression (for an account of the development and decline of Cartesian mechanics in the 18th century see Iltis, 1973b). The study of textbooks shows that different positions existed side by side and arguments were presented for one position or the other. Important concepts were preserved against extinction by the coherent network of mutually supporting ideas in which they were embedded so that they could mature in interaction with contrary ideas embedded in alternative networks. For example, aspects of the notion of impetus were preserved in the systems of Descartes, Leibniz and Newton and these remained as consistent parts of the widely accepted system of mechanics at the end of the 18th century (see, for example, Young, 1807).

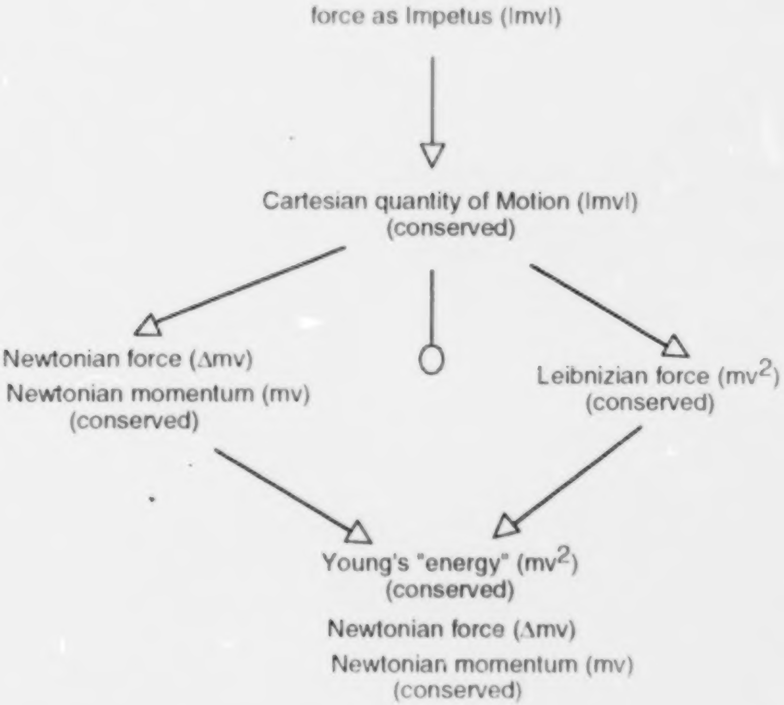
force as Impetus ($|mv|$)
Cartesian quantity of Motion ($|mv|$)
(conserved)
Newtonian force (Δmv)
Newtonian momentum (mv)
(conserved)
Leibnizian force (mv^2)
(conserved)
Young's "energy" (mv^2)
(conserved)
Newtonian force (Δmv)
Newtonian momentum (mv)
(conserved)

Fig 1. Transformation of ideas of force in the 17th and 18th centuries

IMPLICATIONS FOR TEACHING

Some of the issues which were central to debates about dynamics in the 17th and 18th centuries are still issues which those learning mechanics must deal with. These relate to questions such as: What are the properties of objects which are relevant in the study of mechanics? What is inertia and how does it differ from mass? How do the forces of resistance arise when one body collides with another? How can the concepts of impenetrability and inertia help to understand the mechanism of collisions? Why is action equal to reaction in every situation? Why do elastic bodies behave the way they do? The list of important questions to which pupils need answers is endless.

If historical change is any model for rational conceptual change in the classroom it is also important to help students to express and develop, in a coherent way for their own phase of development, the frameworks which contains their own answers to these interrelated questions before confronting them with alternative ways of understanding the same situations. In this way the point of departure is always what they believe rather than simply what they are told.

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CONCEPT SUBSTITUTION: AN INSTRUCTIONAL STRATEGY FOR PROMOTING CONCEPTUAL CHANGE

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ABSTRACT

Numerous studies have shown that students often hold conceptions that conflict with accepted scientific ideas, both prior to and after instruction. The failure of instruction to affect students' conceptions can be interpreted as a failure to facilitate conceptual change. In this paper, an instructional strategy will be described that facilitates conceptual change in the special case where conceptual difficulties appear to arise because students confuse related physics concepts. The strategy involves two parts. Firstly, students observe an experiment or demonstration that conflicts with what they expect to see. Secondly, the instructor identifies students' intuitions that are correct but that they have associated with an incorrect physics term, and substitutes the correct physics term. Students can thus develop more scientifically acceptable understandings of physics concepts without having to give up their intuitive ideas. The use of this strategy will be illustrated in two domains of physics.

INTRODUCTION

The science education literature is replete with reports of studies showing that students often hold ideas about scientific concepts that conflict with scientifically acceptable ideas (see Pfundt & Duit, 1991 for a bibliography). Moreover, numerous studies have shown that such ideas frequently persist even after traditional forms of instruction. This indicates that traditional instruction does not necessarily affect the ideas that students bring with them to the instructional setting or that they formulate for themselves. From a constructivist perspective, students do not learn by receiving intact information that an instructor transmits to them. Rather, students construct their own knowledge on the basis of incoming information that is filtered by their experiences and what they already know (Driver, 1989).

Since students often have their own pre-instructional conceptions about certain scientific concepts, for instruction to be effective it is vital for the instructor to ascertain what these conceptions are and, in particular, to assess whether or not they are scientifically acceptable. If they are not, then the instructional task should be to facilitate a process whereby students can change their conceptions in order to make them consonant with scientific concepts. An extensive literature on theories of conceptual change and strategies for promoting it exists (see Scott, Asoko & Driver, 1992 for an overview). The three main criteria proposed for conceptual change to occur are that the student should find the new conception intelligible, plausible and fruitful. On the other hand, Hewson and Thorley (1989) add that students are unlikely to change their conceptions if they feel dissatisfied with the new concept because they find it counter-intuitive. This last point is particularly relevant to the strategy described in this paper. It would appear that if insufficient consideration is given to students' ideas then scientific conceptions may be rejected by students (Gunstone, 1990), at least on all but a very superficial level.

This paper describes a strategy for promoting conceptual change that is applicable under certain specific circumstances. One source of apparent misconceptions is that students sometimes associate their intuitive ideas with incorrect physics concepts. Thus, although the idea may be correct in terms of describing physical phenomena, because the student has linked it to an inappropriate term, the correctness of the intuition may be overlooked by instructors, and both instructor and students may think that they should abandon their idea. Concept substitution is a strategy whereby the student's correct intuition is identified and reinforced, but the instructor substitutes the correct physics term for the one the student used. In this way the concept being studied can be freed of inappropriate conceptual baggage, while the students do not need to suspend their intuition.

The use of concept substitution in two domains of physics — electricity and mechanics — is described. The strategy has been highly effective in helping students learn to distinguish between closely related concepts and thereby overcome "misconceptions" that have been shown to be very persistent in other settings (e.g. Minstrell, 1984). The research was conducted within the context of a Physics course that forms part of the Science Foundation Programme (SFP) at the University of Natal. The SFP is a one-year pre-degree programme designed to enable academically talented but underprepared black students to succeed in tertiary studies in science or applied science (Grayson, 1994). The strategy was used with the 32 SFP students in 1992 (in mechanics) and the 35 SFP students in 1993 (in electricity). Where student responses are quoted, the reader should bear in mind that the students are second or third language speakers of English.

CONCEPT SUBSTITUTION IN ELECTRICITY

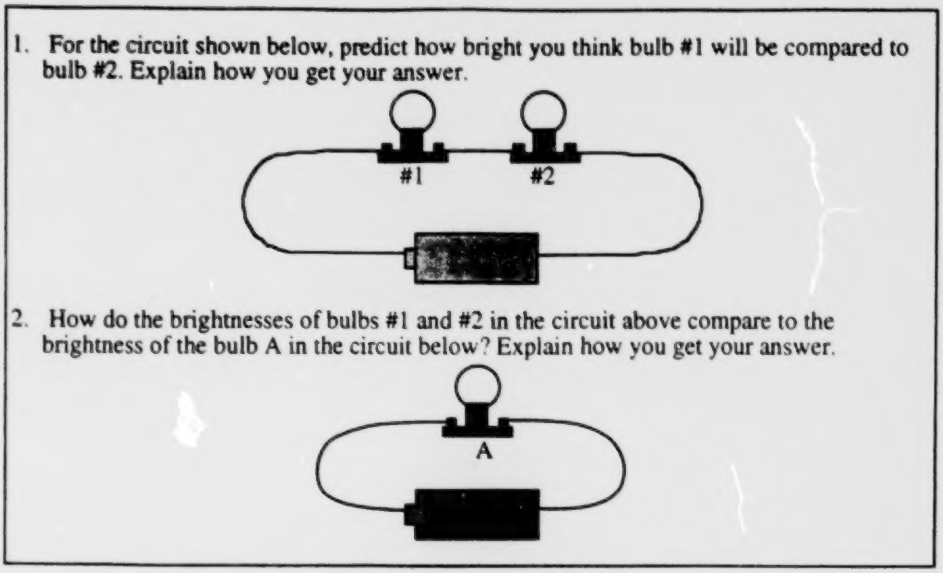
Much research conducted on the learning of electricity has led to the identification of numerous conceptual difficulties (Duit, Jung & von Rhöneck, 1984). Two prevalent difficulties are the beliefs that current is used up in a circuit and that a battery supplies a fixed amount of current, regardless of what is in the circuit (McDermott & Shaffer, 1992a; Shipstone, 1985; Shipstone et al., 1988). To test for the presence of these beliefs among the SFP students, the pretest shown in Fig. 1 was administered at the beginning of the section on electricity.

In response to Question 1, about 30% (11 of 35) of the students thought that bulb 1 would be brighter than bulb 2. Below is a typical student response, indicating that the idea that current is used up in the circuit is indeed present:

> Bulb 1 will be more brighter than bulb 2 because bulb 1 determines how much current will pass through and current will arrive at 1 and be used there and the rest will then pass to 2.

In response to the second question, 20% of the class (7 of 35) thought bulb A would have the same brightness as either bulb 1 (if they thought bulbs 1 and 2 would be different) or as bulbs 1 and 2 (if they thought they would be the same). The following typical response indicates that the students did believe that the battery supplies a fixed amount of current, regardless of what is in the circuit:

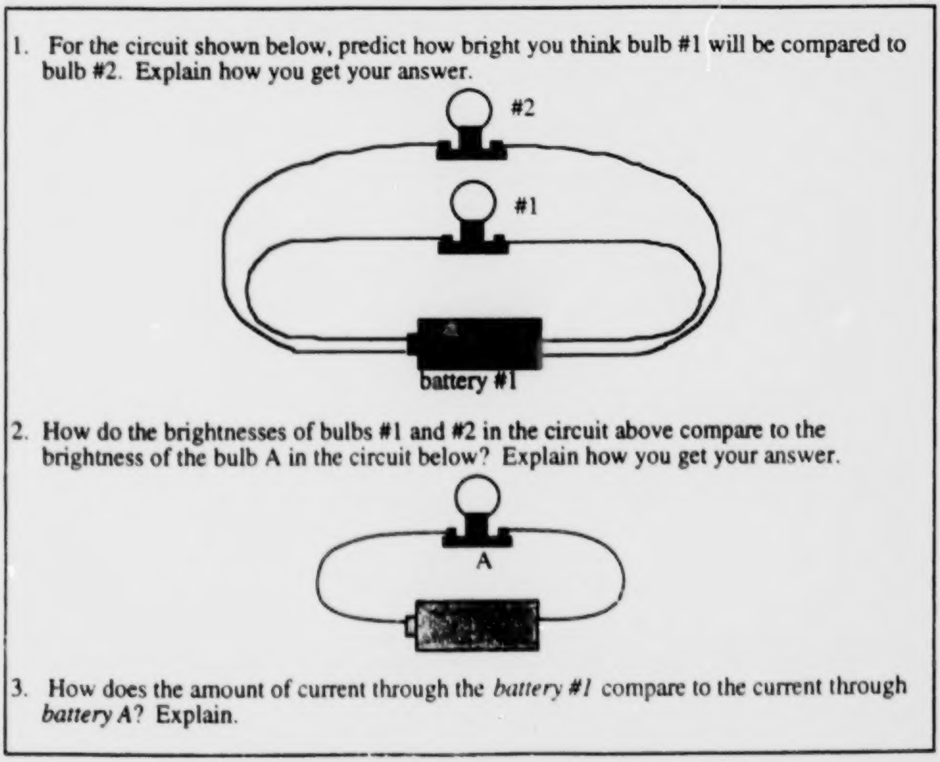
> The brightness of the bulbs above will be the same as that of bulb A because they are all connected to the same battery which give[s] each bulb the same current.



1. For the circuit shown below, predict how bright you think bulb #1 will be compared to bulb #2. Explain how you get your answer.

2. How do the brightnesses of bulbs #1 and #2 in the circuit above compare to the brightness of the bulb A in the circuit below? Explain how you get your answer.

Fig. 1 First electricity pre-test



1. For the circuit shown below, predict how bright you think bulb #1 will be compared to bulb #2. Explain how you get your answer.

#2
#1
battery #1

2. How do the brightnesses of bulbs #1 and #2 in the circuit above compare to the brightness of the bulb A in the circuit below? Explain how you get your answer.

A

3. How does the amount of current through the *battery #1* compare to the current through *battery A*? Explain.

Fig. 2 Second electricity pre-test

Concept substitution - 'energy' for 'current'

After the students completed their written predictions and handed them in, I set up a circuit in the front of the room consisting of a battery in series with three bulbs, with the switch left open. Students were asked to share their predictions about what would happen when the switch was closed. A very lively debate ensued. As expected, a large fraction of the class argued that the bulb closest to the end of the battery from which they thought the current flowed would be brightest, and the other bulbs would be less and less bright. After allowing students to present and argue their cases, I closed the circuit and the students saw that the bulbs were equally bright. The instructional strategy up to this point resembles what Champagne et al. (1985) call "ideational confrontation".

At this point concept substitution was employed. I told the students that they were right to say that something is "used up", but the "something" is chemical energy, which gets converted to other forms of energy. That is why batteries go flat. Current, on the other hand, just goes round and round the circuit. Thus the students could retain their correct idea, but distinguish it from the concept under study, namely current, by pinning their intuitive idea to the label "energy". The strategy of separating out the notions of energy and current has also been used successfully by Johsua and Dupin (1987), although they used it in the context of a modeling analogy. I then told the students that we would assume that the brightness of the bulb indicates the amount of current flowing through it (McDermott & Shaffer, 1992b), after which students predicted the behaviour and observed demonstrations of several multi-bulb series circuits.

Before the next lecture students did a two and half hour practical on multi-bulb circuits (series and parallel combinations of bulbs) and measuring currents using ammeters and nichrome wires (of different lengths) instead of bulbs.

Concept substitution - 'constant voltage' for 'constant current'

At the beginning of the next lecture students wrote responses to the questions shown in Fig. 2. Nearly all students realised that both bulbs in Question 1 would be the same brightness. However, in Question 2 about 70% of the students (25 of 35) said bulb A would be brighter than bulbs 1 or 2. The notion that a battery supplies a fixed amount of current seemed to be the source of the problem, as suggested by the following typical response:

> Bulbs 1 and 2 will be less brighter compared to bulb A. The current in the two circuits is the same, but in A it only supplies one bulb. So all the current goes to the bulb but in battery 1 the current is likely to be divided to bulbs 1 and 2.

In response to Question 3 nearly 75% (26 of 35) of the students said the current flowing through the two batteries would be the same. A typical response:

> The amount of current through battery 1 is the same as the amount of current through battery A because the amount of current flowing through the battery does not depend on the number of bulbs in the circuit.

As in the previous lecture, after students handed in their predictions I set up two circuits in the front of the room with the switches open. One circuit consisted of two bulbs in parallel with a battery and the other consisted of a single bulb and a battery. Students proffered and debated their predictions as a class. When the switches were closed students saw that the bulbs were all the same brightness, demonstrating that branches of a parallel circuit are essentially independent (when internal resistance can be ignored). Thus each bulb in each branch glows with the same brightness as the bulb in a single bulb circuit. It then follows that the current through the battery in the circuit with two bulbs in parallel must be twice that in a single branch circuit.

At this point concept substitution was again used. I told the students that they were right to say that something about the batteries is the same, but the "something" is called voltage. The battery is not a source of constant current. Current depends on what is in circuit. Adding bulbs in series provides more of an obstacle to flow, so there will be less current; adding bulbs in parallel provides more paths so more current can flow. Students were shown two more demonstrations of multi-bulb parallel circuits in order to reinforce this concept, which included inserting ammeters into the circuits to measure the current.

As an aside, one effect of this approach of allowing students to make and debate their own predictions was that after about 15 minutes of debate, students were very keen to see what would happen, i.e. they had some investment in learning this particular bit of physics. This is in contrast to the traditional mode of instruction in which so much information is "covered" so quickly that students do not get a chance to see that certain questions are rather complex or interesting. A possible consequence of the traditional approach is that students may not take note of certain points because they have not had a chance to realise that they are noteworthy!

Evidence for conceptual change

This section will indicate the extent to which lasting conceptual change appeared to occur. The questions from assignments referred to come from McDermott (in press). Six days after the class period described in the previous section, students handed in answers to the questions shown in Fig. 3, given as part of an assignment. In response to Question 1, only 9% of students (3/33) incorrectly said the current was constant. In response to Question 2, only 12% (4/33) incorrectly agreed with Student 1.

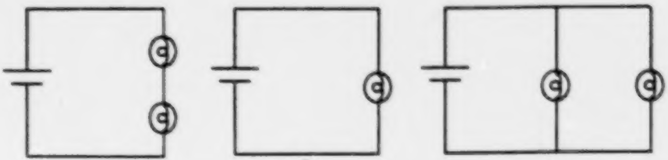
Twenty days after instruction students handed in responses to two more questions that required them to say whether several fictitious students' responses were correct or not. The questions and the relevant fictitious students' responses are shown in Fig. 4.

A student who thought that the battery supplied a fixed amount of current should agree with Student 1 in Question 1. Only 12 % of the class (4/34) incorrectly said student 1 is right; all the rest gave the correct answer. An indication of the degree of understanding most students seemed to have acquired by this stage is given by the following response:

> Student 1 is incorrect because we can't say something in the circuit gets all the current because there is no fixed amount of current in the first place. To correct 1 I would say that A = B = C because since A and B and C have the same resistance and B and C are connected directly to the battery, they demand more current from the battery to keep them burning like bulb A (depending on their resistance).

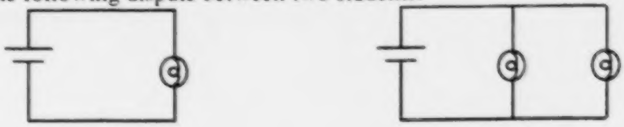
Any student who still thought that current gets used up in a circuit should agree with Student 3 in Question 2. Only 18% of the class (6/33) agreed with Student 3 and thought that current gets used up; the rest disagreed. Of those who disagreed, 70% used the words "current is never used up" in their responses. The extent to which students seemed to have incorporated the notion that current does not get used up into their own understanding is suggested by the responses below, in which students were able to modify and elaborate the answers of the

1. Place the following circuits in order according to the amount current through the battery. Explain your reasoning.



(a) (b) (c)

2. Consider the following dispute between two students.



(a) (b)

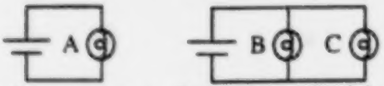
Student #1: The current through the battery in each circuit is the same. In circuit (b) the current from the battery is divided between the two bulbs - so each bulb has half the current through it that the bulb in circuit (a) has through it.

Student #2: We know the current through each of the bulbs in circuit (b) is the same as through the bulb in circuit (a). That's because the bulbs are all about the same brightness - and bulbs that are equally bright have the same current through them. So the flow through the battery in circuit (b) is more than that through the battery in circuit (a).

Do you agree with Student #1 or Student #2? Explain.

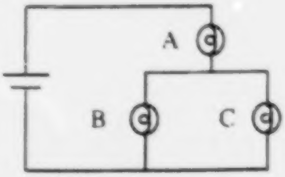
Fig. 3 Questions from a homework assignment given six days after instruction

1. In this exercise, three students give predictions and explanations for the relative brightness of bulbs *A*, *B* and *C*. Say whether each student's reasoning is correct or not. If it is incorrect, say why.



Student #1: B and C will be dimmer than A. Bulb A gets all of the current from the battery but B and C have to share it.

2. In this exercise, four students give explanations for the observation that the identical bulbs *B* and *C* are dimmer than *A*. Say whether each student's reasoning is correct or not. If it is not correct, explain why.



Student #3: Bulb *A* uses up most of the current so less is left for *B* and C. *A* is therefore brighter than *B* or *C*.

Fig. 4 Questions from a homework assignment given 20 days after instruction

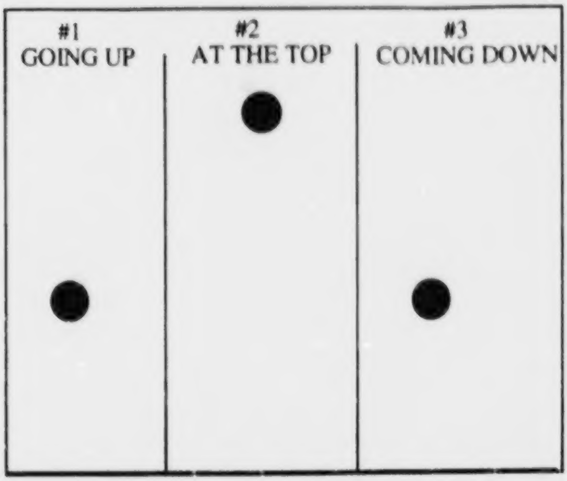
"students" in the question. The quality of these explanations is particularly impressive considering the fact that for these students English is their second or third language.

- Student 3 is incorrect because current isn't used up, energy is. The current through A will be the same as that in B and C except that before B and C current divides. Some of it goes to C whilst some of it goes to B.
- Student 3 is incorrect because current is never used up but the current which was gotten by A is now divided between B and C thus they will have less brightness than A.

CONCEPT SUBSTITUTION IN MECHANICS

The concept of force has provided a fertile field for the identification of students' non-scientific conceptions (Gunstone & Watts, 1985; Hestenes et al. 1992; McDermott, 1984). In studies conducted on student understanding of force it has been found that many students believe that if an agent sets an object in motion the force "of" the agent continues to act on the object while it is moving, even though the agent is no longer in contact with the object (Osborne & Gilbert, 1980). Various authors have suggested that this interpretation may arise from a confusion between, or perhaps a lack of differentiation between, the concepts of force and momentum (Watts & Zylbersztajn, 1981) or force and energy (Watts, 1983). Niedderer (1987) suggests that students may hold "cluster concepts", that is, general umbrella concepts that can take on various specific meanings in particular situations. For example, students may have a cluster concept of force that subsumes aspects of energy, momentum, impulse, inertia, and power. In this section I shall show how the use of concept substitution helped students distinguish between the concepts of force and momentum.

The mechanics section of the Physics course began with kinematics and then went on to dynamics. At the beginning of the dynamics section students wrote a pretest in which they were asked to draw arrows on a ball that had been thrown into the air for three positions of the ball, going up, at the top and coming down (Fig. 5).



A ball is thrown vertically up in the air and then falls back down. For the 3 positions shown draw arrows on the balls to indicate any forces acting on the ball. Make the length indicate the relative size of the force and show the direction of the force. Label each force.

Fig. 5 Mechanics pre-test

83% (25/30) of students indicated an upwards force acting on the ball, at least in Position 1, and many also showed such a force in one or both of the other positions. Many labelled this upwards force the "force of the hand" or the "force of the thrower," and nearly all of the students indicated it was larger than the downward force in Position 1 by drawing a longer arrow.

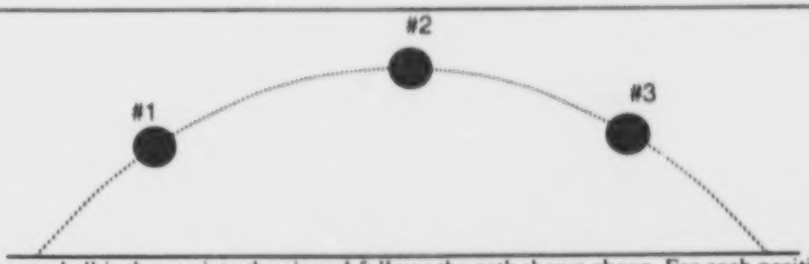
Concept substitution: 'momentum' for 'force'

When we went over the pretest in class, I drew the correct forces on the diagram. Students were very puzzled that there was no force due to the thrower, and argued with me at some length! After all, something must be causing the ball to move, and what could it be other than the thrower? This is where concept substitution was employed. We discussed the fact that the students were right to say that the thrower imparts something to the ball. However, the thrower cannot exert a force when he or she is no longer in contact with the ball, so the "something" imparted by the thrower is not force but another quantity which we call "momentum". A similar conceptual differentiation is suggested by Osborne (1985).

In the next lecture, I introduced the concept of momentum more formally as the product of mass and velocity, and explained that it is conserved unless some force acts to change it. I did demonstrations with a block of ice on the table top at the front of the lecture theatre, showing that if I applied a force for a short time, the ice would acquire a certain velocity and hence momentum, which it maintained after I stopped pushing. If I pushed for a longer time, the ice acquired a larger velocity, and hence larger momentum. We went on to discuss how a longer application of a force causes a greater change in momentum, leading to the relation $Ft=D(mv)$. The point of this discussion was to help students distinguish between the force exerted by my hand while it was in contact with the ice and the "something" that goes with the ice block when I was no longer touching it, namely momentum.

Evidence of conceptual change

In a quiz eight days later students were asked to draw force arrows on a ball that was thrown in a parabolic trajectory (Fig. 6). Although nearly all of the students had drawn a force arrow in the direction of motion on the pretest, in the quiz only one student indicated that a force from the thrower acted on the ball, a significant improvement.



Suppose a ball is thrown into the air and follows the path shown above. For each position shown, draw arrows on the ball to indicate all forces that act on it. Label each force.

Fig. 6 Mechanics quiz

In the final examination several weeks later, students were given a question that stated, "A girl throws a 200 g ball into the air so that it follows the path shown. She exerts a constant force of 5 N on the ball for 2 s before it flies into the air", accompanied by a picture of a ball following a parabolic trajectory. Four ball positions were labeled, namely in her hand (A), going up (B), at the top of the trajectory (C) and coming down (D). Students were asked to draw force arrows on the ball in each labelled position and to label the force arrows. Only one student (of 32) indicated an upwards force on the ball in any of Positions B, C, or D. All of the other students drew correct force arrows for the ball when it was in flight, except for two students who drew longer force arrow due to gravity at Position C than at B or D.

CONCLUSION

In this paper I have illustrated the use of an instructional strategy for promoting conceptual change called concept substitution, and demonstrated its effectiveness. Ideas that have been deemed persistent misconceptions in other studies appear to have been remediated for many students in this study. Of course the question is why should this approach be so successful?

I suggest there are three reasons. Firstly, students did not have to relinquish their own, intuitive ideas, ideas which make sense to them and in which they have some investment. Secondly, by reinforcing students' correct intuitions but giving them another label, students can pin their intuitive ideas to this new term and so free up the concept under study from inappropriate associations. Thirdly, the fact that students feel they have some right ideas probably has a motivating effect on the amount of effort they are willing to put into making sense of the physics. The fact that the learning appears to be lasting strongly suggests that the new ideas do indeed make sense to the students. An added benefit to the approach is that when the concept that was substituted is treated more fully in class, students already have some ideas about it and so instruction does not need to start from scratch.

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AN EXAMINATION OF THE PREDICTIONS AND EXPLANATIONS OF PRE-SERVICE NURSES ACROSS A RANGE OF CONTEXTS INVOLVING THE SAME PRINCIPLES OF FLUID PHYSICS: A PRELIMINARY STUDY

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ABSTRACT

Fifteen first-year nursing students individually took part in structured interviews in which a range of devices related to nursing practice and fluid physics was considered. Analysis of the transcripts of these interviews revealed that although respondents had already completed the section of their course related to fluid physics, the majority still exhibited inconsistent and naive ideas about the fluid state, pressure and fluid flow. After structured intervention however, some responses in the latter portion of the interviews gave evidence of conceptual development and an increasing ability to generalise physical principles in contexts not previously encountered.

INTRODUCTION

As a part of their normal activity nurses control, monitor or use fluids in order to promote the health of their patients (Cree & Rischmiller, 1991; Robards & Welch, 1991). Hence it could be expected that members of the nursing profession would develop an integrated structure of ideas about the physical interactions of fluids. This paper is derived from the initial part of a larger study examining the manner in which concepts of fluid physics are understood by both pre-service and practising members of the nursing profession. The data presented in this paper arise from interviews with nursing students at the end of the first semester of their course and after they have completed that segment of biophysical science which involves fluid physics. The paper examines the qualitative nature of their understanding of such concepts as states of matter, pressure, the effect of pressure on gases and the relationship between pressure differences and fluid flow. In addition, the study was also directed toward testing those factors (outlined below) which are thought to bring about change in personal conceptualisation within the sciences. This paper reports the results of both activities.

It is through the memory of past interactions with familiar objects that individuals develop their early and informal ideas about physical relationships (Driver, 1981). While these ideas permit individuals to make sense of their world (Driver, 1990; Fensham, 1993), they nevertheless appear primitive, naive and fragmented when compared to scientific knowledge. Research over the past two decades has detailed some of the characteristics of these preconceptions that relate to fluid physics. For example, young students found it difficult to accept that air has weight and they often overlooked the effects of air pressure when explaining such phenomena as drinking through a straw (Sere, 1982; Stavy, 1990). They perceived enclosed air as variously being able to 'suck' (de Berg, 1992), to exhibit an absence of pressure (Sere, 1982), or to exert a pressure in one direction only (Engel-Clough & Driver, 1985). They believed that a vacuum must be filled and would therefore create 'suction' (Sere, 1985) and many often saw the magnitude of pressure as being a measure of the 'strength' of the 'suction' (Engel-Clough & Driver, 1985; de Berg, 1992). Some suggested that enclosed air could only exert pressure if it was heated (Sere, 1982) or if movement took place (Sere, 1982; Engel-Clough & Driver, 1985). On some occasions 'gravity' and 'air pressure' were invoked interchangeably when explanations were provided (de Berg, 1992). Some students related hydrostatic pressure to the amount of water present rather than to the height of the water column (Engel-Clough & Driver, 1985). When giving explanations, some students were unable to relate the effects of two or more systems (de Berg, 1992), grasped at irrelevancies (Stavy, 1990) or spoke in anthropomorphisms (Engel-Clough & Driver, 1985). Elements of these beliefs were found to persist through to the end of high school (de Berg, 1992).

If beliefs of the nature of those above are as resilient as has been suggested (Driver, 1990; de Berg, 1992) then it will take more than a teacher at the blackboard to encourage meaningful development. Tobin (1987) argued that a key factor to effective learning was 'active engagement'. This includes involvement with things (direct experience and experimentation) and ideas. The latter is more effective if the engagement includes systematic, reflective thought about personal or vicarious experience (Mayer, 1983). While Driver (1990) emphasised that instructors must provide those experiences that enable students to relate their understanding of science to familiar events and phenomena, she argued that experience alone was not enough. Student thinking should be challenged by a process of intervention and negotiation that questions the integrity and consistency of personal thought and which provides alternative views. In addition, Yager (1991) suggested that students should be guided in the skills of logical thought. That is, teachers should model the logical process before their students. This suggests that in order to alter students' conceptual thinking, students must be exposed to direct experience accompanied by a flow of information; directly questioned about their understanding of the experience or information in such a way that inappropriate or inconsistent ideas are challenged by comparison with more appropriate concepts; and guided in the skills of logical thinking. These three considerations formed the basis of the research method of the present study.

METHOD

Subjects

Fifteen pre-service nurses from a class of thirty-two volunteered to be interviewed about their understanding of the principles of fluid physics. Of the fifteen, eleven were female and nine were under 21 years of age. Ten respondents entered the course through matriculation, two were overseas students, one came through foundation studies and two had successfully attempted some undergraduate subjects toward a Bachelor of Science degree in other institutions.

Procedure

Interviews with the volunteers were audio-taped and were of 45 to 60 minutes in length. Prior to the interviews, a protocol was established on the basis of the following principles.

- The respondent was asked to manipulate the device and to predict and/or explain the observed phenomena.
- Initially, specific terms (for example, 'pressure') were not used by the interviewer until such times as these terms had been used by the respondent. However, if the terms were not forthcoming, cues, clues, questions and ultimately specific pieces of information were judiciously and progressively made available in a manner meant to provoke reflective thought and conceptual change.
- Once specific terms had been raised, their meaning for the respondent was elicited by subsequent questioning.
- While the interviews were intended to be open-ended, questions were deliberately sequenced in such a manner as to provide a guide in thematic logical thought.

The devices shown in Fig. 1 were chosen because they provided a simple demonstration of the principles of fluid physics and in one way or another they were related to apparatus involved in nursing practice. All the devices involved the production of fluid flow (devices 1, 3,

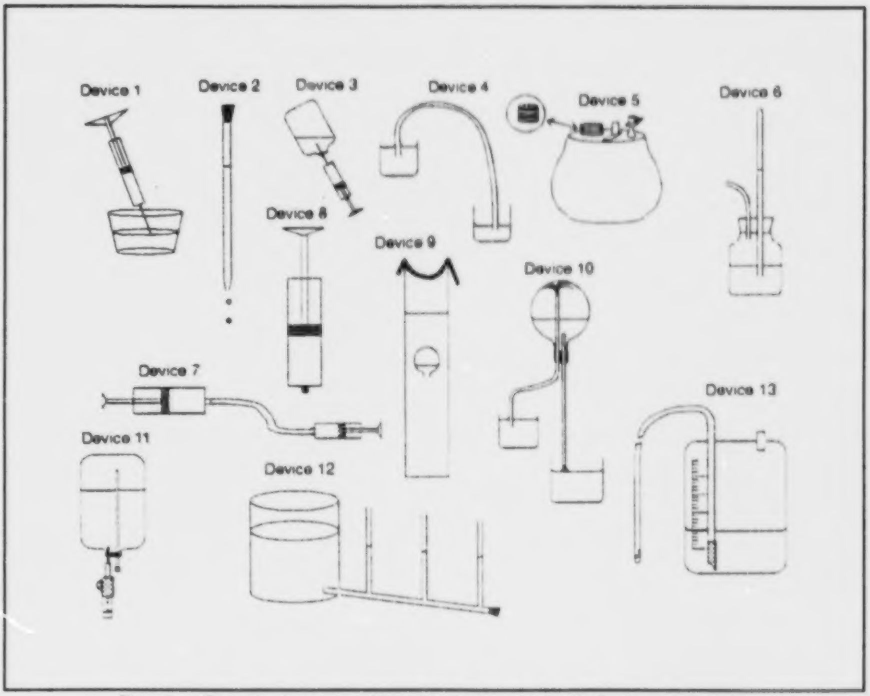

Fig. 1 The devices employed in the study with first-year nurses

4, 5, 6, 10, 11, 12 and 13), the cessation of fluid flow (2 and 11), or the movement of an object as action or reaction (7, 8 and 9). Operation of these devices involved the principles of hydrostatic pressure, atmospheric pressure, Boyle's Law for enclosed air, Pascal's principle and fluid flow due to a pressure gradient. Device 5 was an evacuated drain bottle commonly used in hospitals. Its seal was broken by a respondent while it was held submerged in a bucket of water. Device 13 was an underwater seal accompanying a thoracic drain. The pressure inside the seal was gently reduced by an aspirator. Respondents were asked to explain the principles that underlay its operation.

RESULTS AND DISCUSSION

A preliminary analysis of the transcripts indicated that the nursing students who took part in the study held ideas about interactions with fluids which were anchored in direct experience. However these ideas often appeared to be poorly developed and not greatly influenced either by reflective thought or by formal instruction. The language used by the respondents to describe the use of the devices was often loose and imprecise and many of the ideas discussed were not well integrated into a cohesive view of fluid interaction. As a result explanations for phenomena were not consistent and often showed sudden reversions back to simplistic descriptions. In general students were reticent to apply systematic, logical argument in making predictions and when encouraged or led to do so, demonstrated an initial lack of confidence in their conclusions. However, there were circumstances in which learning did take place. This was indicated by accurate identification of factors involved in the functioning

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of the later devices, greater coherence in the ideas expressed and greater precision with which explanations were given.

The significance of direct experience

The results support the contention that, for the individual, direct experience often determines the veracity of an idea or concept. For example all students used the terms 'sucking' or 'suction' at some time through their interviews. This was defended by an appeal to experience. For example, one student described the activity of device 5 in terms of a familiar machine: "It acts pretty much like a vacuum cleaner: it sucks things up." Another defended her use of the term 'suction' by stating "I've felt things sucking ... it [suction] can pull". A third student when asked for clarification as to whether the water in device 5 was being "pushed" or "sucked" into the drain bottle, answered by saying "I suppose pushed. But you know, you can feel things sucking." A fourth student responded to the suggestion that 'suction' was a non-entity by claiming "But it has to be! ... you can make things stick with suction, you can suck things up. You tell me why there's no suction?"

It then appears that for the students who took part in the interview, reality is determined by direct experience. The idea that 'suction' may not be a real physical entity ran counter to an uncritical acceptance of this experience and met considerable resistance from many of the students interviewed, including two students who, while understanding the principles of fluid flow, still favoured a 'suction' explanation. For example one student argued that "the movement of the water to an area of lower pressure [is caused by] sucking." She then added "I don't think of it as water running from high pressure ..."

A number of students demonstrated an unquestioning acceptance of commonly witnessed events and some even indicated a reluctance to try to unravel the physical interactions behind them. For example, when asked to explain the activity of device 1, one student responded by saying "I have no idea ... it is just the thing that always happens." Another said with some exasperation "I don't know ... it works ... do I have to describe it?" Another student, referring to device 2, stated, "Look I don't know ... all I know is ... from experience I suppose ... that when you put the cork in it will stop the flow. It happens ... I don't know why." Later, the same student when predicting the effect of device 4 said "I've seen it before ... its like ... siphoning."

The importance that these students attached to direct experience could have been responsible for another phenomena noticed in the interviews. Repeatedly, students were reluctant to invoke the involvement of atmospheric pressure in explaining events that they witnessed. They had to be pressed to even think about the presence of air, and all indicated some surprise at the effect of opening the drain bottle under the water in the bucket (device 5). It was a complete shock to those who had no expectations, and those who anticipated the entry of the water into the bottle were still surprised at the vigour with which the water burst into the bottle or at the amount of water that ultimately entered. Possibly, since air is such a ubiquitous material - all-pervasive, yet largely unfelt - its involvement in many everyday activities is ignored. Students may have to be actively reminded of its presence and effects. These results are certainly consistent with those of Sere (1982), Stavy (1990) and de Berg (1992).

'Hands on' involvement in learning activities is important for yet another reason. There were no less than twenty-two exclamations recorded. These ranged from "Oh! How cool!" to "Holy dooly! Will it fill right up? ... That's cool!" It is obvious that these indicated surprise or pleasure. As such, direct experience becomes not only a means of creating an immediate significance for students, but it also has the ability to motivate.

Concepts of state, pressure and flow: the basis of structure

Factors related to the physics of fluids cannot really be discussed without also involving descriptions of both the liquid and gaseous states. However only one respondent volunteered the particulate description of gases, and that was not until device 6. In other words, this student attempted to describe or explain devices 1 to 5 without even mentioning the particle nature of a gas. However, her description of "all the little molecules ... being squashed together" was not inappropriate. The other respondents had to be questioned and even prompted in order to describe the particle nature of a gas. No student offered to describe the particle nature of a liquid and in an oversight on the part of the interviewer, no such description was sought.

Once cued to do so, respondents used a range of descriptions for the effect of pressure on the particles of a gas. Gas molecules under increased pressure were considered to be 'condensed', 'concentrated', 'saturated', 'compacted', 'crowded', 'squashed' and 'pushed closer together'. Reducing the pressure allowed the gas molecules 'heaps more room to move', gave them 'a lot of dead space', made them 'not very dense' and allowed them to 'spread out' or move 'far apart'. Liquids under pressure were also described as being 'concentrated'. Obviously all of these have to do with mental images, models or metaphors of the gaseous state. However, as will be pointed out some of these terms could well have led to confusion. Having related the pressure of a gas to the motion of its molecules, two respondents indicated that the state of compression of a gas was associated with the rate of molecular motion of the molecules. That is, on expansion, the rate would slow and on compression it would speed up. For example, one student (S1) described the effect of an increase in volume on a constant mass of gas by stating "There is less pressure in there ... the molecules will move slower in there..." The same student extended this logic to a decrease in volume: " Oh the air has less space so it's (the pressure) gonna increase. Asked to explain this in terms of molecules, S1 responded, "Oh they're moving faster ... they're more crowded." A second student, S2, also argued that a decrease in volume would also result in an increased rate of molecular motion: "Oh they've got faster and compact ... they're closer together so that they hit each other more."

While the rate of molecular motion and the state of compression can be related under special adiabatic conditions, these did not apply to any of the devices involved in this study. From the context of both interviews, the researchers felt that these two students simply related the degree of pressurisation of a gas directly to the average rate of molecular motion.

There was some confusion in relation to hydrostatic pressure. Three students related hydrostatic pressure to the 'amount' of water present, and had to be prompted to be more specific about the relationship between the height of a column of water and the pressure at its base. Yet another respondent indicated that the higher the column of water the greater the pressure - but located the position of maximum hydrostatic pressure as being "further away from the ground, so the higher up here (pointing to the top of the water column), that has more pressure" . The latter response represents total confusion about the cause of hydrostatic pressure.

All respondents viewed pressure as having some type of vector property. Pressure could be 'exerted', it could 'push' water down, 'lift' water up and it could act in specific directions. This of course is not inconsistent with nursing literature for blood pressure is defined as the force exerted by blood on vessel walls (Wolff, Weitzel & Fuerst, 1979). Only two respondents were able to recall the definition of pressure as 'force divided by area' - none indicated that it was the 'magnitude of the force divided by area'. Only the same two students were able to explain the effect of device 7 (the different sized syringes joined by surgical tubing) in terms of force and area. Student S3 provided a rather novel explanation when she described the reason for the obvious difference in the hand exertion needed to compress the two syringes: "It is something to do with the diameter of the thing. You are trying to push from a bigger into a smaller and its harder than trying to push from a smaller into a bigger um area ... It's much easier to go from a small to a bigger one ... It kinda makes sense. When you try to pack things, its much easier to put them into something big than into something small ... the same amount of stuff." The authors found it significant that this student tried to use a common analogy in an effort to 'make sense' of this experience. It certainly has elements of what Fensham (1993) would describe as 'commonsense knowledge'.

All respondents acknowledged that pressure could be transmitted through a fluid. However, only one was able to recall a common definition of Pascal's principle and only five students were consistent in applying the principle. Strangely enough, these five did not include the student who was able to repeat the definition! This suggests that in his case, the wording may have been learned by rote with little real understanding of the actual principle, for he was unable to apply it to explain device 9.

All respondents were able to repeat some form of the proposition that 'fluids flow from high pressure to low pressure'. However only seven attempted, without prompting, to employ this principle to explain phenomena and only four respondents were in any way consistent in applying it as a principle. As already described, two respondents knowingly resisted the use of this principle in favour of a 'suction' explanation. Only two respondents were comfortable with the idea that the human body could be regarded as being 'under pressure', and that drainage of bodily fluids into the evacuated drain bottle was an application of this principle rather than that of 'suction'.

Confusion and imprecise use of language

All students at one time or another responded to questions inappropriately, incorrectly or loosely. For those who generally displayed greater understanding these instances appeared to be periods in which they played with ideas before tightening their response. However, for others this inappropriate pattern of response was consistent and may well have been due to a fragmented idea structure that caused them to respond with some totally unrelated ideas or to focus upon obvious but irrelevant physical attributes of the device or upon some prominent but equally irrelevant aspect of the environment. For example, to the question, "Why is the water going into the syringe?" (device 1) the initial response of two students was 'osmosis' or 'osmotic pressure'. Although one student (S4) knew enough to correct herself she provided a clue to her thinking. This respondent used the term "less concentrated" and "more concentrated" to describe the molecular state of gases under varying conditions of compression. In this situation, water was going "into" something - cell or syringe - and it was going into "an area of lower concentration" (her words). Similar wording is often used to describe the process of osmosis. The lack of any real mental 'picture' of the activity and an undue reliance upon limited and imprecise wording could well have created the initial confusion. In device 2, a number of respondents appeared to focus upon the cork without really examining the effect that its presence might have. For six students, the cork "stopped" air from entering the tube. They were unable to further qualify this statement without prompting. Two stated that the cork caused a 'vacuum', another said that it caused 'suction' and two more stated that it somehow interfered with the action of 'gravity'. These results are consistent with those of de Berg (1992) who used the same device when examining English students up to the age of 18 years.

Respondents often blended loose terminology with imprecise conceptualisation. One respondent suggested that "gas particles expanded to drive water out". Another spoke of "unequal gravitational force". A number of respondents used the term 'diameter' when it was obvious they meant 'area' and others spoke of 'area' when they should have been talking about 'volume' and two others confused 'gravity' and 'pressure'. In three cases when the term 'diameter' was used the contexts revealed that the respondent was in fact focussed up the physical size of the syringe or tube.

Respondents often slipped into animistic descriptions. Such terms included expressions like "the water wants to go in" or "the pump wants to pull the air out". In a number of cases, the context indicated that the use of these expressions could have been related to limited mental imagery, an inability to relate physical principles to specific examples or an inability to use specific language. For example, consider the following dialogue:

Int: Why was it that the water flooded inside [the drain bottle]?
S3: It seems like it got sucked in. [Int: Mmm] Mmm. [Laughing] Elaborate on that thought?
Int: Yes elaborate on that thought.
S3: It sort of got sucked in ... as if the bottle wanted it to go in.
Int: Do you think that air pressure had anything to do with it?
S3: Isn't it always like trying to find equilibrium ... coming to an equilibrium or something?

In this passage it seems as though the animism was thrown in because S3 had not accommodated her thinking to the presence and effect of air pressure and therefore was unable to apply the principles of 'fluid-flow'. Even the cue lacked real significance for her.

Development in the use of a physical principle to explain the observed phenomena

To this point, it might appear that the knowledge of these students was fragmented and fixed. However, it is not a complete picture. It was the intention of the process to challenge the students' current knowledge through a blend of direct experience and persistent, sequential questioning. Only two consistently demonstrated fragmentary knowledge throughout their interviews. Nine demonstrated unquestioned but uneven development in the way they perceived the principles of fluid physics during the progression of the interviews. Four gave evidence of a strong propensity for reflective thought and an ability to use logic in an appropriate sequential manner and hence showed the most consistent use of physical principles. Because of the lack of space, only two transcripts will be included (Boxes 1 and 2). Student S5 demonstrated real growth as she progressed through the devices. Early in her interview, S5 did not employ the principles of 'fluid-flow', but rather spoke in terms of 'suction'; she did not invoke air pressure in her explanations; she appeared to have a hazy understanding of hydrostatic pressure and appeared unsure of the principle of pressure transmission throughout a fluid. However, Box 1 demonstrates that by device 12, she was able to respond to the sequenced questions and was therefore able to predict the various water levels when the cap was removed from the horizontal tube. Her exclamation, ("Ah ha, it did work!") expressed a satisfaction that her deductions were correct.

The second transcript was of student S1 who was taken back to device 1 after completing all devices (see Box 2). In her first attempt at explaining device 1, she used a 'suction' argument and did not employ atmospheric pressure at all. However, on her return to device 1 she deliberately discarded the 'suction' argument in favour of the use of atmospheric pressure and the 'fluid-flow' principle. She too expressed delight at her success ("See I know that now - I've learned something.").

CONCLUSIONS

This study has revealed that the ability to give clear and unambiguous descriptions of observed phenomena is dependent upon a number of factors. The most basic of these relates to a clear conception of the particle model of the fluid state. Without this students find great difficulty in understanding fluid pressure and fluid flow. Secondly, in order to give

BOX 1 - STUDENT S4 WITH DEVICE 12

Int: Which way is the water going to flow [when the cap is removed]?
S5: Along here and out there (indicating the direction in the horizontal tube from the jug to the capped end).
Int: Right. Where is lower pressure going to be?
S5: Here (pointing the capped end).
Int: Yes. Where's the higher pressure going to be?
S5: In the jug at the bottom.
Int: All right, so what can you tell me about the pressure through this line?
S5: It will be high at one end and low at the other.
Int: Good. Now what's going to happen between.
S5: The pressure will drop.
Int: Fine, so what will happen to these levels?
S5: The one closest to here will be down and the one closest to the jug will be up.
Int: Now that's good reasoning. Pull the end off and just watch what happens.
S5: Ah ha, it did work!

BOX 2 - STUDENT S1 AND DEVICE 1

ON FIRST TRY
Int: Right, what I've got here is a beaker with water inside and I've got a syringe with a needle. Would you put about 5 mls of watnr into the syringe for me?
Respondent places the needle into the water and draws back on the plunger.
Int: Okay, why was it that the water rose up inside the syringe when you pulled back on the plunger?
S1: Oh because it is sucking it up through the needle.
Int: Hmm 'sucking it up' . . . is there any thing else that could be involved?
No response.

ON RETURN TO DEVICE 1 AFTER COMPLETING ALL BUT ONE DEVICE
Interviewer takes the syringe, places the needle into the water and draws the plunger.
Int: Why did it fill up with fluid? When you pull the plunger back, what are you doing inside the syringe?
S1: (Laughing) We're increasing the volume . . so the pressure is going to be less and the high pressure from the atmosphere pushes it up. I thought before it was like pulling it out that sucked it up, but maybe its the air pressure. . . . See I know that now - I've learned something!

adequate explanations, students need to have a clear understanding of the terminology involved. Finally, unambiguous descriptions are also determined by the student's ability to argue in a sequentially logical manner. This paper provides evidence that these skills can be developed by a combined approach in which the student is provided three things. The first is a practical experience within the context of the profession. The second is an environment in which they are led to reflectively contemplate on the ideas arising from that experience and weigh them against the suggestions from other sources. Thirdly, the student should be provided with an example of the systematic use of logical thinking.

This paper has emphasised the difficulty that an individual faces in forming an integrated idea structure that is compatible with accepted scientific theory. Even by the end of secondary school and the commencement of professional training students still exhibit fragmented concepts that could well impinge upon their professional function. However, one must realise that the students who took part in this study have yet to enter the clinical phase of their education where nursing knowledge may well assume more of a procedural character and their understanding will become more professionally practical. The extent to which the scientific knowledge of fluids should enter the professional knowledge of a nurse needs clarification through further research.

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LEARNING TO LEARN IN INFORMAL SCIENCE SETTINGS

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ABSTRACT

Visits to museums and science centres are a part of most school science programs - but are they really learning experiences? By accompanying classes on visits and talking with the teachers and students during and after these visits, information has been gathered on the ways in which school groups currently use visits to two informal science learning settings in Sydney - a science education centre and a large museum. Comparison of the teacher and student behaviours on these visits with current views on good teaching/learning practice, reveals considerable anomalies. At the same time, reported studies of museum visitors suggest that family groups use museums for learning in ways which are quite different from the way most school groups do. Can these apparent mismatches be translated into a pathway for developing new approaches to learning in informal settings?

INTRODUCTION

Over the past twenty years there has been an avalanche of changes to our knowledge about the ways in which children learn, particularly in science, and some change to classroom practices. These changes are evident in national and state curriculum statements and syllabuses. During this same period, museums have been modifying their understanding and approaches to their audiences, recognising the need to present information in a way which is more closely linked to the interests, attitudes and entering behaviours of their visitors. This paper argues that there has been little interweaving of these changes in classroom and museum education practices, with the way in which school excursions to museums are conducted, and that the structures generally imposed on these visits by teachers impede learning. Few studies in Australia have looked at what happens on museum excursions, particularly in Australia, from the school class perspective. The study reported here describes the way in which schools currently use museums for excursions in Sydney, and compares this with the 'natural' learning patterns of family groups.

Price and Hein (1991) summarise extensive work on successful group use of museum visits, and conclude that important features of programs which engender long-term learning and interest, are: planning; consideration of the unique learning opportunities of the institution rather than mirroring school-type use; variation in the activities during the visit; sparing use of worksheets; and emphasis on first-hand experience and observation. A number of studies have shown that students who have done work on a topic at school before visiting a museum and who have prepared for their visit learn more from their experience (Delaney, 1967; Koran & Baker, 1978; Gennaro, 1981; Reynolds, 1984). Falk and Balling (1982) found that without orientation and preparation, students concentrate on non-task relevant aspects of the surroundings, rather than those relevant to the learning intended.

Despite this evidence, it is doubtful that many school group visits to museums in Australia actually reflect any of the successful strategies discussed in the literature. It is vital that this mismatch be addressed, considering the substantial educational and economic investment in such activities.

THE STUDY

Over a three month period, 114 interviews were conducted with teachers and students from 13 schools. These schools were visiting one of two institutions: the CSIRO Science Education Centre, which takes single classes for hands-on experimental sessions, or the Australian Museum, a large natural history museum. The groups were randomly selected from classes of Year 5 to 10 students, already booked in to the institutions. This range was selected to fulfil two criteria: the students were old enough to be reading worksheets and working independently; they were in school years where teachers have some personal choice about the curriculum they are following with their class. The interviews with students and teachers covered the purpose and expectations, as well as preparation and follow-up to the visits. The actual behaviours of teachers and students during the visit were also observed. All interviews were taped and transcribed.

Small groups of two to four students were selected randomly by the interviewer. As far as possible, all teachers accompanying the excursion were interviewed individually. As the class entered the institution, groups of students were taken aside for an informal discussion based on a pre-determined set of questions. Further groups of students were interviewed during and towards the end of the visit. The teachers were each interviewed once during the visit. Within two weeks of the excursion, the interviewer visited the school and talked with randomly selected groups of students, and with the teachers. With some classes whose visit took place close to the end of the school year, this follow-up visit was not possible.

FINDINGS

The results of all interviews were grouped to give a summary pattern for each school. For the purpose of this paper, differences between primary and secondary, or between the institutions being visited have not been analysed. This will be the subject of a further study. The school's pattern of responses to each of the major aspects investigated in the interviews have been categorized into three groups, indicated in Table 1 as 'None' (indicating that this aspect was reported as not addressed at all), 'little' (little was done), or 'satisfactory' (this aspect was reported as being done to a satisfactory level.

TABLE 1
SUMMARY OF INTERVIEW ANALYSIS

	Percentage of schools		
	none	little	satisfactory
Teachers' objectives	7	53	40
Students' knowledge of purpose	46	31	23
Teachers' description of preparation	31	54	15
Students' description of preparation	43	43	14
Teachers' involvement in museum learning	15	31	54
Students' involvement in museum learning	8	46	46
Teachers' follow-up plans	9	56	36
Students' follow-up expectations	20	80	0
Actual follow-up - teachers' views	44	33	22
Actual follow-up - students' views	45	45	10

Although the planning, preparation, purposes and apparent outcomes of these visits varied widely, a number of clear patterns emerged. These will be discussed individually. Most school groups fell into one of two quite distinct groups: the majority, in which the educational outcomes were doubtful, and a smaller group which could be considered successful or at least potentially so. In a number of groups in this second category, the planning and objectives were very positive, but for various often logistical reasons, the achievement of these plans was hampered.

Preparation for the visit

The overwhelming pattern was that very little preparation is done for these excursions, and what is done is normally purely organisational. The students of one school (Year 10) were unaware of which museum they were visiting as they got on to the bus that morning. Most student groups had been told that they were going on an excursion to the museum or CSIRO, what money it would cost, that they had to bring a permission slip from their parents, and at best given the worksheets to look at the day before. The students had a varied understanding of the purpose, and the topic, of the visit. However, there were some striking exceptions. One class (Year 5) had been working for some time at school on the topic of their visit, and had been well prepared on how to use the museum's exhibits:

> She told us on Friday [that] there is things that you can do around here, like not just something you can look at and turn to the other thing and look at that, [but] to read the plaques and see what happened and why.

This particular class did not have worksheets; however, they were observed comparing one exhibit with the next, showing each other things that they recognised, asking each other and their teacher questions about the displays, using all aspects of the exhibit: the hands-on and computer displays, as well as the real objects and the labels. They continued interacting with the exhibits for more than half an hour in each of two galleries. This was the only group who mentioned anything about discussing what to do in the museum before they came, apart from disciplinary cautions.

One group was involved in the planning of the route of the visit. This was a mixed group from two schools: students from a country school were visiting and being billeted by students from a city school. The visit to a museum was 'a day out for the visitors' (they also visited the zoo on this day). The city students who had been to the museum before, helped to plan what they would look at in the museum, and the teacher developed a route based on these requests.

Relation to work being studied at school

Only four of the school groups were actually studying the topic of their visit at school at the time of the visit. Several groups had done the topic earlier in the year, however the relationship of this visit to the topic was not made clear to the students. Very few students could see a purpose for their visit other than a day out, or at best "to learn things", but with no clear idea of what these "things" were. In one instance where teachers were rotating their classes through several topics, the teacher who was taking the topic that related to the visit was starting with a new class the next day. On that day, immediately following the visit, when he was starting the topic of fossils, he did not mention the visit to the museum!

What happened during the visit

In all the groups that were observed the teachers were involved with the students to some degree throughout the visit. This involvement ranged from actively working with a range of small groups of students as they looked at the exhibits and answered questions on their sheets, through working quite specifically with one or two small groups and ignoring the rest, to very superficially watching the group, mainly for behaviour, by standing back and not participating in the learning activities at all. In only one instance did the teacher actually leave their group to have a cup of coffee: and she left them in the care of a parent at this time. On many occasions however the teacher sat down at least for a short time.

The students in most instances were quite actively involved in the galleries and using their worksheets for about the first half hour. After this, their behaviours varied considerably, from finding the coffee shop, to sitting (and lying) on gallery benches, sitting on the floor copying each other's worksheets, or moving very quickly from gallery to gallery if they were allowed to move on their own. A few of the groups continued looking at the exhibits throughout the visit.

At the science education centre a similar pattern emerged, although there was a much higher incidence of students continuing to be task-oriented throughout the visit. At this centre the teacher's behaviour again varied,with many teachers standing back and not actively working with the students at all.

Worksheets and views of learning

At the science education centre the worksheets are provided at each activity station. However, not all the students used or collected these sheets. More than a third of the students interviewed were not working through the sheets as intended. At the museum, all but two of the groups brought worksheets with them. In all but one of these cases they were based very closely if not completely on sheets provided by the museum education staff. When asked about worksheets, most students said they did not like them, as they restricted what they saw, and they were boring (one group had actually completed exactly the same sheets on a visit to the museum two years earlier). In answer to questions about what they would rather do, most students said they would prefer to look around without sheets They felt that the imperative to have the sheet completed to hand in at the end was very constraining and stopped them looking at the exhibits, particularly it stopped them from having any choice regarding what they looked at.

In spite of this, they often commented that they "wouldn't learn anything" if they didn't have the sheets. There seemed to be a strong belief that "just looking around" did not count as learning. This idea became apparent very early in the interviews. Questions like, "What did you learn on your visit?", or similar, were fruitless. The answer was, invariably, "nothing". Following on the experiences of Falk and Dierking (1992) the students were asked instead about what they remembered. This brought answers about specific displays which they had seen. When the idea of learning was discussed further, particularly when associated with worksheets it became very apparent that the students did not believe they were learning unless they were answering questions on their worksheets. They seem to identify learning almost exclusively with the type of activities which go on at school, especially pen and paper activities. While several groups said they would prefer not to have worksheets in the museum they added, "but you wouldn't learn anything if you didn't".

This restricted view of learning was also apparent when their views of what they had learnt in the discovery space were elicited. The discovery space is a dedicated hands-on area of the museum, which has a mainly environmental theme. One group in particular which used this space was adamant that "you don't learn anything in there - you play" . Interestingly it seemed that most teachers had the same view. If the students did ever get the chance to get into this room, they were generally chased out again by the teachers, so they could get back to "the real learning" in the specified galleries. Only one class was intentionally taken to the discovery space by a teacher.

Social groupings
The students enjoyed working with and talking with their peers. With only a very small number of exceptions they did not like having to complete a worksheet each, they preferred to do this as a group. All classes broke into small groups who moved, talked and worked together.

Follow-up after the visit
The students often expressed a more realistic view of the follow-up activities than the teachers. Most of the teachers said that they would do something, although this often consisted of collecting and marking the worksheets. The students had low expectations that there would be any work done back at school based on the visit, beyond collecting the sheets. When interviewed after the visit, the results showed that indeed there was very little done - less than the teachers had expected.

There were again some striking exceptions to this pattern. One Year 6 group who had visited the science education centre, spent some time discussing their experiments in class and sharing what they had found out. A Year 10 teacher had asked the students to select an experiment at the science education centre, and do follow-up experiments at school based on this. Unfortunately end-of-year interruptions prevented this from taking place. A third school held extensive class discussions based on the questions they were asked to answer at the museum, looking for evidence for different theories.

In addition to the intended outcomes of this research, regarding preparation, implementation and follow-up, several other issues emerged which will guide the further development of this study.

Student and teacher attitudes
There was clear agreement between the teachers and students on attitudes to the visit as a worthwhile learning experience. If the teacher had a clearly defined purpose and an enthusiastic positive attitude to the day, the students reflected similar attitudes. If the teacher was bringing the class because this was the day allocated to bring Year 10 to the museum, and had no clear goals or expectations, the students' attitudes, expectations and general behaviour matched. This attitude match was also apparent, when looking at specific parts of the museum. The one class that was taken to the Discovery Space by their teacher, was left there in the care of a parent while the teacher went and had a cup of coffee. It was these students who told me: "You don't learn anything in there, it's a place to play"!

Teaching strategies
While at the museum, most of the teachers appeared to abandon what would generally be considered basic good teaching practice. With some exceptions, there was a general pattern of unclear goals, lack of variation in learning activities, poor preparation on the part of the teacher, and no link with classwork, or contexts relevant to the students.

IMPLICATIONS

Consideration of these results in the light of literature on childrens' learning in science, and on family group visits to museums revealed two major sets of anomalies.

Mismatch 1 Comparing the strategies used by the majority of teachers who were observed, with strategies which would indicate understanding of the ways in which children learn science, a startling mismatch emerges:

- The students were generally given no control whatsoever over their learning . At the museum, they were given no choice in what they studied or which parts of the museum they used to study it. At the science education centre however, the students could at least choose which experiments to do, as the centre is set up in this way.

- The information they were studying in either venue was not placed in context for the students: neither the context of their school studies, nor made relevant to their own experiences.
- The teachers generally did not act as model learners. In the instances where this did happen there was a dramatic effect on the students. They gathered around the teacher and were interested to learn with them.
- There was little evidence among the majority of teachers that they were really interested in the students actually learning anything - there was more emphasis on completing the tasks set, and getting home again without anyone getting into trouble at the institution.
- The teachers did not have clear goals or objectives for the day.
- The students were given one learning strategy and expected to stick with that for 1½ to 2 hours - in a classroom a teacher generally changes strategies about every 15 minutes.
- The teachers generally did not participate in the learning of the students - they allowed most of the students to fend for themselves.
- They used teaching materials with which they were not familiar (the displays) or which they had not prepared or modified to suit their class (the worksheets).
- They did not link this learning episode with others before or after.

Mismatch 2 There is a considerable range of literature on the ways in which family groups use museums. These include studies on viewing and movement behaviour patterns; length of stay in each exhibit and in the whole museum; social interactions; what they like to see and what they remember; orientation behaviours; attitudes and motivation (Falk, Koran & Dierking, 1986; McManus, 1992; Falk & Dierking, 1992)

A number of authors also discuss the differences between formal and informal learning, and how informal learning environments differ from formal learning environments. A look at some summaries of the differences between formal and informal learning will highlight this mismatch. Falk and Dierking (1992) and Ramey-Gassert, Walberg and Walberg (1994) have each summarised the literature to show the characteristics of an informal learning setting. Box 1, based on their summaries, lists some differences between characteristics of formal (school) and informal (museum) learning.

BOX 1

Informal Learning	Traditional Formal Learning
Voluntary - attendance	Compulsory - attendance
- choice of exhibits	- choice of exhibits
Unstructured	Structured
Unsequenced	Sequenced
Non-assessed	Assessed
Non-competitive	Competitive
Open-ended	Closed
Learner-centred	Teacher-centred
Contextually relevant	Relevance unclear
Heterogeneous visitor groupings	Homogeneous visitor groupings
Non-curriculum-based	Curriculum-based
Many unintended outcomes	Any unintended outcomes are disregarded
Collaborative	Individual

These sets of characteristics, when compared to the findings in this study, indicate that school teachers are imposing all of the features (and restrictions) of formal learning onto an informal setting. Neither teachers nor students have a very clear idea of how to use a museum, what its purpose, uses or benefits are as a learning environment. An immediate response to this discussion might be that we should abandon organised school visits to museums altogether, however it is also clear that they can have benefit for the students, (Gennaro, 1981; Stronck, 1983; Price & Hein, 1991; Tuckey, 1992).

The need emerges, then, to find different ways of organising, planning and running school visits to informal science education settings, in order to maximise the learning potential. Central to this is the education of teachers on the use of a museum as a learning venue. Hein (1990) describes the way in which school teachers regarded the Exploratorium, in San Francisco, "as an authoritative resource", and expected their students to approach it similarly. This was in opposition to the philosophy of the Exploratorium itself which was to empower the learners. He concluded: "If the museum was to have a liberating effect on the teaching of science to children, it first had to change the attitudes of the teachers." (p.132). While teachers have started to change the way they facilitate learning in their classrooms, these new approaches and strategies have not been transferred to the running of excursions to informal learning settings. A number of museums have surveyed the public to discover their attitudes and reasons for visiting, and found a persistent view that museums are stuffy, untouchable, and unchanging: this despite dramatic changes in virtually all public museums, including emphasis on touch displays, regularly changing exhibits and a much more user-friendly approach. Many museums are now moving toward an increasing number of hands-on exhibits, as considerable research (e.g. Koran et al., 1984) has indicated that these increase attention and curiosity, vital components for learning. And yet teachers do not take their students to major hands-on sections of the museum, and tend to pull the students away from such exhibits. It would appear that teachers have not changed their views on how museums should be used as learning environments for their students. In an informal evaluation done for the Australian Museum, interviews with adolescents indicated that students have a negative stereotype of museums, based on excursions which they considered to be too controlled and structured

The results of this study, in the light of reported information on learning in science, and on 'natural' learning by family groups in museums, have fostered the development of some tentative views on different ways to approach museum visits. These approaches incorporate the following ideas:

- Use what has been learnt about the ways in which students learn science and apply the subsequent approaches (such as 'learners' questions') to topic studies which incorporate a museum visit as one of the learning strategies. In particular, develop learner-centred approaches where the students are finding answers to their own questions, rather than the teachers' or the museums'. An alternative approach might be that the students walk out of the museum with a list of their own questions to study further, rather than walking into the museum with someone else's.
- Apply researched best practice in teaching to museum visits.
- Apply the practices and behaviours of the natural learning methods of family groups to school classes when they visit an informal setting.
- Recognise that different learning styles, approaches and strategies need to be used in this very different learning environment.

The challenge is to formulate more appropriate ways of using museums for learning, and to do this within the existing constraints of time, expense, and experience. This next stage in the study will look for ways to engage formal education with informal settings in a meaningful and productive partnership.

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TECHNOLOGY EDUCATION AND SCIENCE EDUCATION: ENGINEERING AS A CASE STUDY OF RELATIONSHIPS

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ABSTRACT

Technology education and science education are seen to be related in a particular fashion by many science educators, a relationship exemplified by the common pairing of the two areas in labels such as "Science–Technology–Society" and "Science and Technology Curriculum". At the heart of this common science education perspective is a view of technology education as dependent on and subservient to science education. In this paper engineering, often seen by scientists as a form of applied science dependent on and subservient to science, is considered. An analysis of the arguments that engineering, far from being an applied science, is a unique way of knowing (that engineering has a unique epistemology) is used to consider the technology education view of the relationships between science education and technology education. It is suggested that science educators need to rethink their perceptions of this relationship if they are to understand the arguments of technology educators.

INTRODUCTION

One obvious feature of curriculum developments in science education in the last decade has been the growth of use of the label "technology". This has been via the growth of curriculum emphases exemplified by the descriptor "Science–Technology–Society", and by the at times Pavlovian association of "Science and Technology" as a label for a general area of curriculum. However these science education perspectives are frequently at odds with that which is the concern of those promoting technology education as a new focus for schools. Science education has, in essence, embraced technology as a means of providing relevance for the learning of science by including in that learning education about the applications of science. Technology education has a clearly different vision.

This is not a new argument. Fensham (1990, 1992) has written persuasively about technology education's view of the inappropriateness of the notion that technology education is education about the applications of science (see also Scriven, 1987). The purpose of this paper is to reinforce these arguments by considering a situation which I argue to be closely analogous. This is the discipline of engineering. By considering the perspectives of engineers about the epistemology of this area of knowledge, and by contrasting this with the common science perspective about the nature of engineering knowledge, the differing perspectives on technology education held by science educators and technology educators can be illustrated.

ENGINEERING AS A CASE STUDY

The use of engineering as a case study does not mean that this paper is concerned with the general nature of relationships between science and technology. Those relationships are complex, although often distorted through simplification by science and scientists, and are a crucial aspect of the complexities in the relationships between science education and technology education (see, for example, Gardner, 1992, 1993.) However the focus here is on just one discipline, engineering, and the relationships between that discipline and science as seen by scholars of engineering.

Why engineering?

I do not explore engineering because of any perception of engineering being equivalent to technology – such a perception would be contentious. Engineering has been chosen because the relationships between science and engineering, I argue, have significant parallels with the relationships between science education and technology education. The parallels are particularly valuable in terms of how each group in these two pairings (science-engineering; science education-technology education) sees itself and the other member of the pairing. The most obvious example of this is that just as science tends to see engineering as "applied science", as dependent on and subordinate to science, so science education tends to see technology education as "applied science education" and thus dependent on and subordinate to science education. In both cases the supposedly subordinate other member of the pairing rejects this perspective, and for the same broad reasons.

Engineering as a way of knowing

The essential purpose of this section, I reiterate, is to outline the perceptions of engineers of the discipline of engineering and to consider differences between engineers and scientists in terms of the perceptions of each group of the relationships between engineering and science. Some may feel that the views of engineers about engineering are overstatements (although I do not). This does not impact on the argument of this section of the paper: that it is necessary for science to recognize and accept the legitimacy of engineering's views of itself and engineering-science relationships, even though these views are at odds with those of science. In this context it is also important to note that I am using the label 'science' to denote those intellectual pursuits which are concerned with generating understandings of the physical and biological worlds, 'traditional science'.

In this section I am attempting to set out briefly a complex and multifaceted view that engineering is a unique way of knowing. The difficulties of being brief about this lead me to draw heavily on the arguments of Goldman (1990). However Goldman is far from alone. Arguments with the same general thrust as his have been advanced, for example, in the more specific context of aeronautical engineering (Vincenti, 1990) and in the wider case of technology in general (e.g., Ferguson, 1992; Layton, 1974). The essence of the engineering view of that discipline as a way of knowing separate from science is summarized by Goldman (1990):

> Scientific knowledge and engineering knowledge are two fundamentally different kinds of knowledge, and, bizarre though it may sound at first hearing, they have different worlds as their objects (p.126).
>
> Crudely put, science has as its central activity generating descriptions of the ways things are. Engineering has as its central activity generating things that have never been (p.135).

There are a number of possible beginning points for elaborating this view of different worlds. Most helpful for the purposes of this paper is how the particular is seen in science and in engineering. For science, the particular has importance as an instance of a generalizable statement (a concept, a principle, a law, etc.). "...the particular is so much better behaved in the world of the scientist than in the world of the engineer that, as it can be deduced from the universal, its particularity can be ignored" (Goldman, 1990, p.126). For engineering, in contrast, the particular is the focus of the investigation, and so that which makes it particular remains central. This is at the heart of the contextual dependency of the solutions to engineering problems (and, in passing, it is a reinforcement of these differing views of the particular that scientists send to talk of "questions", engineers to talk of "problems"). Because solutions to engineering problems are solutions to contextually bound issues, with the context being an inseparable component of the problem, then these solutions "have a particular, arbitrary and contingent character" (Goldman, 1990, p.127). Even the problems are overtly invented in response to the particular, and often by other than engineers. This is in stark contrast to science where the questions ("problems") are almost exclusively generated by scientists and are seen by practising scientists as exploring an already existing reality.

These different approaches imply that different forms of reasoning are typical of science and engineering – and this is indeed argued by those who propose engineering as a unique way of knowing. For example:

> ...the objects of engineering reasoning are far more complex than the objects of scientific reasoning; the former, unlike the latter, never lose their particularity and are explicitly inseparable from the intentional, contingent, willful, and value-laden contexts of their formulation (Goldman, 1990, p.129).

The issue of different forms of reasoning is best illustrated by considering the central place of design in engineering problem solving. The process of design in the creation of solutions to engineering problems (which, it has been argued, are necessarily contextually bound) "mandates a form of reasoning...that is fundamentally incompatible with the universal, context-free [science] conception of rationality traditionally promoted by philosophers and embedded in modern mathematics and physics" (Goldman, 1990, p.129).

It might be seen that a counter to this argument is that, today, there is much greater acceptance of the notions of science being a human activity, of science being a human construction, of rationality not being absolutely context-free. That is not the central issue. More significant is the concept of universality. In science, or at least in that form of science one can describe as European or Western science and which is ubiquitous in our schools, the intent is to seek the (current) best description of/explanation for a phenomenon. Where competing descriptions/explanations emerge, resolution involves determining which is the (currently) better; the other(s) are discarded. That is, science has a fundamental epistemological assumption that there will be one (currently) best theory. The replacement of that theory with another is widely held to be the consequence of new intellectual activity, albeit with some passage of time and the overcoming of resistance from individual scientists. Engineering, on the other hand, often is just not seeking the "best" solution in this way. For example, consider the conclusions of Waldrop (1989) about the variations in control systems introduced by different manufacturers of commercial aircraft.

> So, who's right? Maybe everybody. It's a cliché that engineering is an art, but it is. And it's perfectly possible for Airbus, McDonnell Douglas, and all the rest to come up with very different solutions to the problem of aircraft automation, and still be perfectly correct. (p.1534)

That is, each of these different solutions is argued to be "best" in the specific context in which it is being used. Even in engineering contexts where the science concept of "best" solution is less inappropriate, best will not be exclusively determined by a set of universal engineering principles. A range of issues associated with the particular problem (potentially embracing economic, political and cultural) will contribute to the determination of best. That is, the particular remains central; the nature of the reasoning used does not admit the science assumptions of the pre-eminence of universality and the existence of unique best explanations. "Engineering knowledge is distinctive for being driven by the search for consciously non-unique solutions to explicitly invented problems" (Goldman, 1990, p.134).

This brief discussion of differences between science and engineering has focussed on the different views of the two disciplines about the significance of the particular and of universality. This does not exhaust the issues which are seen by scholars of engineering to reveal different epistemologies for science and engineering. Among other issues not addressed above is the view that, as engineering always involves action on our world, questions concerning the appropriateness of this action are embedded in engineering itself (e.g., Goodman, 1970). This leads to the argument that constructs such as morality and aesthetics are necessarily a part of engineering, while these constructs are seen as external to the discipline of science.

Relationships between engineering and science

The purpose of considering engineering as a way of knowing was, primarily, to provide some means for considering views of science-engineering relationships. Science, I have already argued, tends to see this relationship as "engineering is applied science". The above outline of aspects of the engineering view of itself makes it clear that engineering does not see the discipline as applied science; indeed the science view of engineering, as characterized above, has no relevance to the engineering view of engineering discussed here.

> The crucial point to appreciate is that engineering on its own activity generates knowledge. It does not passively wait for knowledge to be given to it from a different community of practitioners in order for it to attempt increasingly complex enterprises (Goldman, 1990, p.141).

Further, as already argued, that knowledge which engineering seeks to generate is not "science knowledge". When compared with science, engineering knowledge is characterized by quite different views of the particular and of universality; it is, in the terms of the first quote from Goldman given in this paper, a fundamentally different kind of knowledge about a different world. Thus, while engineering and science are related, engineering is not subservient to science; while science is a tool which engineering will often choose to use, engineering is not dependent on science. It is not science with applications. Engineers see engineering, science, and the relationships between the two disciplines to be very different from the ways science sees engineering and the relationships.

> Engineers generate the knowledge that they need, to solve the problems they define, in terms they assimilate. To do so, they selectively appropriate scientific knowledge, in the process transforming it into engineering knowledge (Goldman, 1990, p.128).

This conclusion about engineering as a unique way of knowing I argue to have direct parallels with science education-technology education relationships. To make this point I now very briefly review the views of technology education that are argued by science educators and technology educators.

TWO VIEWS OF TECHNOLOGY EDUCATION

The views of science education

Essentially these views are that technology education is a means of creating relevance for science education. Perhaps the most obvious example of this is the British SATIS (Science and Technology in Society) Project. The motivation for this project is summarized in the Project's General Guide for Teachers:

> Much has been written and said about the lack of relevance of the secondary science curriculum; its dryness, its impersonality and its excessively academic content. Introducing social and technological aspects into the science curriculum helps to make science more relevant in a number of ways (Holman, 1986, p.13).

This is technology used as "add on" applications for the purpose of enhancing student interest in science per se (Fensham, 1990, p.120). Approaches described by Fensham (1990) as "whole-hearted or central", such as the British Salters Science materials, place technology in a stronger position in recognizing that "the science knowledge of an application is not the same as science knowledge with applications" (Fensham, 1990, p.13). However this is still technology used to enhance science education. What little data is available suggests that this is how science teachers see technology education (Jones & Carr, 1992).

The views of technology education

Technology educators do not accept these science education perspectives. Their vision is quite different. Consider, for example, the description in the Victorian Technology Studies Framework: P-10 (Maruff & Clarkson, 1988).

> Technology studies is an area of the curriculum in which students...learn about:
>
> * materials (what it is made of)
> * engineering (putting it together and making it work)
> * systems (the whole, not just the part);
>
> by being involved in a process of:
>
> * designing it
> * making it, building it, doing it
> * testing it;
>
> which gives them
>
> * a body of knowledge and a repertoire of skills
> * personal enrichment and self-esteem
> * an enhanced ability to cope in society
> * an orientation to the future and to change. (p.7)

There are two issues in this description of specific importance to the arguments of this paper. First, note the implicit focus on the particular in the description (what IT is made of, putting IT together, what makes IT go, designing IT, ...). Second, consider the sequence in the description. In this technology educators' perspective on technology education it is the processes of design/make/test "which gives" students "a body of knowledge...". This is obviously different to the science education perspective on technology — that the learning of a body of generalized knowledge then allows the student to apply this knowledge to design/make/test. The parallels with the differing science and engineering perspectives on the role of the particular and on the significance of universality are clear. The knowledge being considered in the above view of technology education is a different sort of knowledge to that which is of concern to science educators.

One form of summary of these different sorts of knowledge is given by Corrigan's (1993) summary (Table 1) of Fensham's (1990) description of differences between science and technology.

TABLE 1
A COMPARISON OF SCIENCE AND TECHNOLOGY

SCIENCE	TECHNOLOGY
* takes nature apart in order to understand or explain it	* puts nature together in order to make something novel
* is interested in natural phenomena	* is interested in artificial things
* is essentially analytical in its thinking	* is interested in essentially synthetic problems
* is interested in being able to generalize knowledge by inventing concepts and laws and even ideal situations (e.g. ideal gases; frictionless or unbending surfaces)	* is interested in specific knowledge; knowledge that has a bearing on a real specific context and that provides detail about a specific problem
* is often driven by knowing for its own sake, by a fascination with natural phenomena	* always has a human need or opportunity in mind
* is basically comfortable with notions like "discovering" or "uncovering" nature	* is basically comfortable with notions of "design" and "invention"

(Corrigan, 1993, p.11; after Fensham, 1990)

A qualifying comment on the two views of technology education

My purpose in describing science educators' and technology educators' views of technology education has been to contrast these. However it should be recognized that these brief descriptions of views of technology education do not give any sufficient sense of the current debate within each view about the nature and role of technology education. Some of the diversity of views within science education has been hinted at in the references to SATIS and Salters Science, but these two cases do not represent all of the diversity of views. (See, for example, Fensham, 1988 for an elaboration of the varieties of STS approaches to be found in curriculum materials at that time.) Technology education is perhaps even more the subject of internal debate about its nature and form. One obvious case of this is the ongoing English debate about the nature and place of design in technology education in that country (e.g., Norman, 1993). However this diversity of perspectives on technology education within each of science education and technology education does not detract from the essential argument of this paper.

CONCLUSION

A consideration of the views of scholars of engineering about their discipline and its relationships with science shows that these views have no similarity with the views of scientists about engineering and science-engineering relationships. As seen from the perspective of engineering, engineering and science are different ways of knowing. Although the disciplines are related each has its own identity; neither is dependent on or subservient to the other. That the relationship is seen differently from the perspective of science does not affect the legitimacy of the argument of "related and discrete" as a description of the science-engineering relationships.

The same broad argument applies to the science education-technology education relationship. The views of technology educators are of technology education as a new and different curriculum area, one which legitimately uses science when it is appropriate to technology education. It is a viable new addition to the curriculum because it values different ways of knowing to those valued by science education. One significant component of these differences is, as for the science-engineering differences, the place of the particular and of universality in these two curriculum areas.

What value is this argument to science educators? Put simply, science educators cannot understand the arguments of technology educators for the place and purpose of technology education while they continue to see technology education as applied science education.

I conclude with another analogy with the same message as the consideration of engineering, an analogy much closer to the heart of the science educator. Consider the relationships between physics education and mathematics education. As a physics teacher I have always felt it absolutely appropriate to see mathematics as a tool I would choose to use when it was appropriate for my physics education purposes. When mathematics teachers told me physics depended on mathematics I knew they were wrong. I knew they did not accept that mathematics and physics represented different forms of knowledge, different ways of looking at different worlds. This lack of acceptance (and therefore of any understanding) of what was to me demonstrable and obvious – physics was not dependent on and subservient to mathematics – sometimes led mathematics educators with whom I worked to do things I regarded as outrageous. An extreme example of this came in a year when I taught the same group of Grade 12 students both Physics and Applied Mathematics. I fiercely resented being told by the external examiner of Grade 12 Applied Mathematics that some students on the external examination in that subject had used methods learned in physics to answer problems. (I had taught applied maths to some of these "recalcitrant" students.) That these students had correctly solved the problems on the examination did not alter his stance – these were inappropriate methods because they were not part of the mathematics curriculum. All rather silly, I believe. Well, substitute "technology" for "physics" and "science" for "mathematics" in this example and you have the essential argument of the paper.

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FIRST-YEAR TERTIARY STUDENTS' UNDERSTANDINGS OF IRON FILING PATTERNS AROUND A MAGNET

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ABSTRACT

This paper describes responses from 28 first-year university physics students to one question of a written test which was followed up by an interview. The study has two main research aims. Firstly, it characterises the conceptual structures of students regarding the phenomenon in question. As well as being interesting in their own right, these student understandings cast light on some broader issues regarding understanding of field representations. While students' understandings of circuit electricity are well described in the existing science education literature, their understandings of field phenomena are not. Secondly, it throws light on theoretical questions about the SOLO Taxonomy, which is the framework used to study the students' conceptual structures. Of particular interest is the nature of student thinking that marks transition from the Concrete Symbolic to the Formal SOLO mode in this area.

INTRODUCTION

The iron filing patterns around a magnet are easily demonstrated and well known; it is general knowledge in our culture that these iron filings "show the magnetic field of the magnet" in some way. This study has investigated students' levels of understanding of the processes behind this phenomenon. As discussed in the conclusion, this has implications for student understandings of broader issues involving fields, especially field lines and the notion of field at all points in space. Their understanding of this concrete phenomenon generally shows little link with the abstract concepts they have studied in their physics course. As well as being valuable in its own right, investigation of these understandings has cast light on theoretical issues regarding the development of the Structure of the Observed Learning Outcome (SOLO) Taxonomy. The SOLO Taxonomy is being increasingly used in science education research, and is still undergoing an exciting process of development.

Understandings of fields

Few papers have discussed student understandings of electric and magnetic fields. Viennot and Rainson (1992, p. 475) stated that "the electric field itself, and more generally the notion of fields, has not been at the centre of any research on students' reasoning". They found that their students, after years of tertiary physics study, were generally unable to reason effectively about interactions between electric fields, as the students could not use the idea of vector superposition. In the present study, students generally failed to apply the idea essential to vector superposition, the idea that a field can be represented by a vector at each point in space.

Törnkvist, Petterson and Tranströmer (1993), in another study of student understanding of electric fields, found that university physics graduates had great difficulty with reasoning involving field lines. They suggested that much of this difficulty was caused by student confusion about the difference between representations of motion in the field and of forces in the field. Their subjects, being graduates, would be expected to have a higher level of understanding than the first-year students in the present study. In particular, some of the explanations given by Törnkvist et al.'s subjects were of a significantly higher level of abstraction than was observed in this study. The present study takes students at a lower level, and asks them a question about a physical phenomenon, whereas Törnkvist et al. asked a question already phrased in terms of field line abstractions. Also regarding field lines, MacMillian and Swadener (1991) conducted interviews with six first-year university physics students about a problem in field interaction. They found that all their subjects had poor qualitative understanding of the problem situation used, and had difficulty drawing meaningful field lines or making qualitative statements about their problem involving electric fields. The present study presents students with visible lines in iron filings surrounding a magnet and leaves it up to them to make connections with "field lines".

Maloney (1985), writing about the relationship between electric and magnetic fields, reported that the students in his sample tended to confuse electric and magnetic fields, and to predict that their effect on a test charge would be the same. Herrmann (1991) suggested that it would be desirable to teach details of magnetic fields by analogy to electric fields, but he did not seem to confront the problem that this might tend to encourage student confusion between the two. This paper reports on student responses to a problem about magnetism, which has bearing on the question of confusion between electric and magnetic fields.

Stocklmayer, Treagust and Zadnik (1994) suggest that a field-based model would be useful for the teaching of introductory electricity and describe a promising trial on classes in year 9 and year 11. An understanding of student difficulties in explaining the field-related phenomenon of iron filing patterns casts light on conceptual structures which is relevant to design of such a conceptually based course with heavy emphasis on fields.

Fergusson-Hessler and de Jong (1987) worked with concept mapping of tertiary electricity and magnetism. They believed that a truly hierarchical knowledge structure covering electromagnetism was not possible on the basis of knowledge available to students in first year tertiary physics. In their study, Fergusson-Hessler and de Jong decided on an ideal knowledge structure 'looking down', from their position as experts in the field, and then analysed their data in terms of students' score in achieving this exact structure. By contrast, this paper examines the knowledge structure of students related to a given phenomenon, describing this structure in itself rather than comparing it quantitatively against some idealised hierarchical structure.

The SOLO (Structure of the Observed Learning Outcome) Taxonomy.

Since its inception by Collis and Biggs (1979), the SOLO Taxonomy has undergone continuous development and evolution. Current theoretical research issues in SOLO are related to the aims of this project.

Other level systems used in education lack a firm theoretical base. With roots in cognitive psychology, the SOLO Taxonomy is distinct from these other systems. The four main modes of response in the Taxonomy are Sensori-Motor, Ikonic, Concrete Symbolic and Formal. Only the last three are of concern in most school learning. Learning cycles are considered to occur both within and across modes, as discussed below.

The SOLO learning cycle progresses through levels. These levels go from unistructural, where one fact about a topic is known, through multistructural, where a number of independent facts are known, to relational, where these facts are integrated through knowledge of the relationships between them. In the original version of SOLO (Biggs and Collis, 1982, p. 216) further growth from a relational understanding can only take place by movement into the next mode of response. This made the Taxonomy rather rigid.

More recently (Pegg, 1992; Levins & Pegg, 1993) there has been a recognition that a relational understanding can become a unistructural component in a new cycle of learning. These learning cycles do not necessarily involve a transition between modes. In school, it is common for students to undergo numerous cycles of learning in the Concrete Symbolic mode, as most school activities are focused towards this mode of operation.

The number of cycles of learning involved in a mode of functioning is a function of the topic involved. A criticism commonly made of SOLO and similar schemes is that they fail to recognise that the structure of learning is partly dependent on the particular area being studied. While the original textbook (Biggs and Collis, 1982) in SOLO is vulnerable to this criticism, the multiple cycles within modes of the current SOLO Taxonomy recognise this partial dependence of structure on subject matter. Hence, more subtle growth in student understanding can be distinguished than was possible using the original version of the Taxonomy.

A current interest in research using the SOLO Taxonomy is to establish exactly where these cycles of learning in the Concrete Symbolic mode take on a different character, and move into the Formal mode of operations. The exact nature of the Formal mode is not fully established in the SOLO Taxonomy, although Pegg and Coady (1993) have identified cycles of learning in this mode. Their data concerned students' understandings of algebraic inequalities. Data is lacking to establish of the nature of Formal thinking about qualitative as opposed to quantitative concepts, although Stanbridge (1993) suggested that it is characterised by student use of abstract models to explain questions. This project, supplying data from tertiary students in physics, was intended to help characterise this shift between modes in student thinking.

THE STUDY

Research questions

Two complementary research questions are treated in this paper. The first question is: what are the characteristics of students' understandings of the iron filing patterns around a magnet? This has bearing on the students' understanding of field lines and magnetic field. As previously stated, little work exists on understandings of field-related concepts. This study presented students with a qualitative physical phenomenon, and tested their ability to spontaneously use concepts involving field lines. This contrasts with the few earlier studies, which started with abstractions such as a field line diagram and required students to work from there; the approach used here seems more likely to expose students' naive conceptions. Analysis of these understandings provided empirical data which helps to answer theoretical questions about the SOLO Taxonomy.

The second question is: what constitutes SOLO Formal reasoning about qualitative questions in this content area? An answer to this question is intended to contribute to the continuing development of the SOLO Taxonomy.

Method

The study (part of a PhD project) opened with a pilot phase where questions were tried out with ex-students and current Year 11-12 students of physics. Following this, in the main phase of the study, the data presented in this paper were collected from first-year university physics students after their course of study in electricity and magnetism. Almost all of the students in this main study had also completed physics in high school, and had hence learned the material twice. It was judged that this amount of exposure was likely to lead to a larger number of high-level responses from the tertiary students.

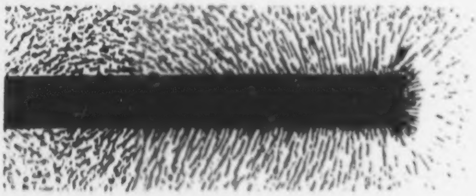
Students were approached during their physics lab classes and asked to fill in a written test of duration approximately 30 minutes. Response rate was close to 50% (n=28 students out of approximately 60 attending the lab classes). Those who responded were asked to participate in a series of three interviews of half an hour each. A small honorarium was paid for each interview to encourage participation. The first interview was used to confirm and clarify students' responses to the written test, with the later two interviews asking the students new questions. All interviews were later transcribed to aid in data analysis.

Data were analysed within the framework offered by the SOLO Taxonomy, that is, with emphasis on discovering the abstract structure underlying the responses. Responses were classified into groups based on qualitative similarity of response. These groups were then examined in terms of the SOLO Taxonomy for the insight they give about the structure of learning in this subject area.

Box 1 shows Q1 in the written test. This question deals with the well-known but generally poorly understood phenomenon of formation of lines in iron filings surrounding a magnet. Explanation of this phenomenon involves some concept of field lines and the nature of the field around a magnet; rather than phrasing a question in terms of these abstract concepts, this concrete example was chosen in order to see what use students made of the concepts in their explanation. This question had been tried out with Year 11 students, and slightly modified as a result. The question was printed in three parts over one and a half sheets of A4 paper in order to encourage lengthy responses from the students.

BOX 1

If you hold a magnet under a sheet of paper covered with iron filings, the iron filings form a pattern as shown.



(i) Explain why this pattern forms. We know large pieces of iron would go to the magnet. Why do the iron filings show the magnetic field of the magnet instead of simply going to the magnet?

(ii) What will happen if an iron filing is dropped into an empty space in the pattern? Why?

(iii) The pattern is now swept away, leaving the magnet by itself. What will happen if an iron filing is dropped where there used to be an empty space in the pattern? Explain why.

In the first interview, subjects were questioned about their answers to the written test, including their answers to this question. Twenty two subjects participated in this interview. The subjects were presented with questions intended both to clarify their written statements and to test their degree of certainty about them.

FINDINGS

On the whole, students did not show a very good understanding of the process which causes the phenomenon in the question. Most tended to take a rather simplistic view, and many were aware that their explanations were incomplete, or even self-contradictory. The students' responses tended towards the Concrete Symbolic mode (n=13) as opposed to the Formal mode (n=11) with 4 being transitional between modes. The levels of description which appeared are shown below.

An example response from a single student has been given for each level. Written responses are indented and marked with an asterisk; these are sometimes followed by excerpts of the dialogue between the interviewer (I) and that student (S).

Level 1: Concrete Symbolic mode of response

Characteristic of this mode was the idea that the filings were simply moving to map out concrete elements. At the unistructural level, the concrete element was the undifferentiated idea of "field of the magnet". In the multistructural level, students started to consider the multiple ideas of field lines, field strength, magnetisation of filings and forces on the filings. A relational level was reached in this mode of functioning when students related these ideas into a consistent picture where filings moved to distinct "field lines" because these were where the field was strongest. Students in this mode generally believed that there were distinct lines of magnetic field separated by spaces. The spaces between these lines were often considered to be areas of lesser or even zero magnetic field. The concrete elements of the field become more complicated with increasing level.

Level 1a): Unistructural Concrete Symbolic. Here, the filings were described as mapping out some sort of undifferentiated "field" of the magnet, which was judged to be a single structure in the student's mind. This level was only seen once in the sample, probably because of the amount of exposure the students have had to field concepts, particularly that of field lines.

* The iron filings follow the magnetic fields [sic] patterns of the magnet

Level 1b): Multistructural Concrete Symbolic. Eight students showed this level of response, where they were beginning to apply the ideas of field lines, field strength, magnetisation of filings and forces on the filings. They still seemed to lack an integrating principle.

* The iron filings are small and light enough to be attracted to the individual lines of magnetic force, thus displaying the pattern.

* It will be attracted to one of the lines of filings. The direction it moves is dependent on the various strengths of magnetic attraction.

* It will be attracted to where there was a line of filings, for the same reason as above.

This student has used the ideas of lines and attraction, but does not seem to have a picture of a mechanism causing the movement.

Level 1c): Relational Concrete Symbolic. Four students displayed this level. They related the ideas of lines of force and movement of the filings. For example:

* The iron filings situate themselves in a position oriented according to the magnetic field.

I [reads from written response]: They "situate themselves in a position oriented according to the magnetic field". Why do they do that?

S: Because that's where the field lines are.

I: So what are you saying, what do you mean by "oriented according to"?

S: Like the filings, you know, the lines, the field lines go like that, sort of curved in. They just gather along the field lines.

* The iron filing will situate itself oriented on the lines of force of the magnetic field.

Use of the word "oriented" here seems to correspond to the idea of "just gather along the field lines", i.e. the naive conception has survived unaltered, although dressed in more appropriate terminology; this student had no written answer to part (iii).

I: You didn't answer it, but if the pattern - you may as well read it. [long pause]

S: It'll just go back into the, move into the pattern.

I: So it'll move to where one of the lines was?

S: Yeah.

I: OK, so would you say why it might do that?

S: Coz that's where the strength of the field is. Or it's more concentrated or something.

This student's conception was based on the simple assumption that if we see a finite number of lines, they must be real. The student has elaborated that assumption by associating these lines with greater field strength. There is a relationship seen between the movement of the filings and these lines of greater field strength. This response is still solidly based on the assumption of a finite number of concrete lines in the field, which are mapped out by the filings.

Level 2: Formal mode of response

In this mode, students realised that the patterns in the filings were caused by some process more abstract than simply mapping out of a finite number of concrete "field lines". To explain this, students used two ideas. First, that filings became magnetised and hence aligned their long axes parallel to the field at that point. Second, that these magnetised filings affected each other by their magnetic fields, which explained the spacing of the lines. A relational level was gained where these two ideas were related to each other and to the formal definition of field lines.

These ideas have been considered Formal as they show signs of using abstract propositions in reasoning. The idea that each filing becomes a magnet is not a directly observable idea - it is an abstraction, especially when the students come to reason about the poles and fields of the magnetised filings. It is the use of this abstract idea in describing physical phenomena that identifies Formal reasoning.

A single cycle of Formal reasoning has been identified in this study. The earlier version of the SOLO Taxonomy (Biggs & Collis, 1982) did not recognise multiple learning cycles within modes. In terms of that model, the Formal learning cycle identified in this paper would be simply development of a unistructural understanding of the Formal concept of field lines. That is, the Formal levels of understanding presented below are fine structure which would not have been recognised as a cycle of learning in the original SOLO Taxonomy.

Transitional Level: Concrete Symbolic/Unistructural Formal. As mentioned above, the ideas of magnetic alignment of filings and magnetic interaction of filings are required to explain the formation of the pattern around the magnet without postulating a finite number of concrete lines. The four students in this category apply one of these ideas, but still cling to the idea of a finite number of concrete lines.

* This pattern forms because of the magnetic field lines cause the iron fillings (sic) to arrange themselves in this order. Because the fillings (sic) are small and movable this allows them to arrange themselves in this order...
I: How do the magnetic field lines cause the iron filings to arrange themselves into this order?
S: I would imagine... like a little magnet, arranged, with the north and the south and there's the magnetic field lines. [pause] Something like that I think... They arrange themselves along that line
I: OK, why should they do that?
S: Because of this magnetic force which is attracted to this north to this south and this south to this north.

Above, we see the student using the idea that the iron filings will form chains due to their induced magnetism, which is a unistructural Formal idea.

* It will join the pattern because it is not in an (sic) line of electric field.
I: Well, what would you say is the difference between a point on a line and a point right next to it?
S: Stronger, stronger on the line. ...
S: I'm going on what the lines are, a physical thing, they're not just, um, something we draw in our books. I'm, um, suggesting that they're actually there.

This is a clear statement that the student still feels a need to assume a concrete cause for the visible lines, and hence is still linked to the Concrete Symbolic mode.

Level 2a): Unistructural Formal. Five students believed that the pattern formed because the filings became magnetised and aligned themselves like tiny compasses. They used the single idea that magnetisation of filings causes them to rotate parallel to the local field direction. Using this reasoning, they were unable to account for the formation of distinctly spaced lines.

* The filings are big enough to align with the field, but are too small to be pulled by it.
* The magnetic field will magnetise the filing, and it will thus align itself with the field.
* Same as in part (ii), and for same reasons.

In the above, the student makes no comment on the formation of distinct lines, so this was taken up in the interview:

I: If you look at the picture closely, it looks like there are distinct lines of iron filings there with distinct spaces between them. Now, would that happen if all that happened was they just swivelled round?
S: Yeah, I see - um depends whether the filings themselves are just round or whether they've got a bit of length to them, coz if they're like scattered about and they align themselves, then they're going to form lines and there's going to be some space in between them - it'll vary but there will be some.
I: Why will there be space between them? Like, if you imagine a crowd where everyone is looking the same way, it doesn't mean that they'll form lines.
S: Yeah, I see what you mean - dunno, forgotten. I knew once.
I: Could you guess?
S: Um, [pause] I couldn't even hazard a guess.

This unistructural level is not sufficient to fully explain the phenomenon.

Level 2b): Multistructural Formal. Five students were at this level. Here, we still have mention of alignment of filings in the magnetic field, as was seen in unistructural Formal. At the same time, we start to see another concept, where the lines are explained by interaction between the magnetised filings. At the multistructural level, these understandings are rather vague, essentially saying that there will be some sort of ill-defined interaction which moves the filings relative to one another. Even so, students are working with the abstract model of invisible magnetisation of the filings, and using it to explain the phenomenon.

* Because every piece of iron has a +ive and -ive end like the magnet. Therefore, the positive ends will form closer to the +ive end and lie in a line in the same direction the field does.

The "+ive and -ive" above shows a confounding between electric and magnetic fields which was common in the sample. This theme was taken up in other questions in the study, but is too complex for inclusion here.

* It will turn it self [sic] until it to [sic] lies as the other will. They all will lay almost equidistant from one another because the filings will have their own little magnetic fields.

* Will align to a magnetic field line.

I: OK, why are they in line? You can see that looks like a line, that looks like a line, why should they form lines?

S: Because that's the direction of the magnetic field - if um - well, it's gotta go - um - well, the field's sorta more denser close to the magnet than it is out, so it makes sense they've got lines, I guess.

I: Why should they form these gaps between them?

S: Coz the filings repel one another.

I: And why should they repel one another?

S: Well, all the filings, the ones in lines, they're going to be positive to negative, all the way around. And - so the filings next door to 'em, they're going to be positive to negative all around... And likewise in the next line, there's going to be the same, irons, positive and negative, so the two positives are going to repel and the negatives are going to repel.

This student has the ideas of magnetic alignment of filings and magnetic interaction between filings, but still has a hazy notion of the nature of the interaction between filings, and lacks a clear overview of the process forming the lines.

Level 2c): Relational Formal. The single student at this level had the ideas about interactions between the iron filings fitting into a framework involving the idea of field vectors, and had a clearer picture of field lines.

* The filings align themselves in the direction of the magnetic field because the field magnetizes (sic) them most effectively along their length...

* The new filing, too, will be magnetized with its own little N and S poles and align itself in the prevailing field... The new filing may well be attracted to, and join, a "chain" of filings along a field line. The fields of each of these tiny magnets reinforce one another.

* The solitary filing will behave almost exactly as if the pattern were still there, though the tendency of the filings to link up may have decreased their motion, i.e., the new filing is likely to stick to the magnet.

S: ...if you have a north pole on its own, with no south pole to the magnet, then it will act in a magnetic field as a proton would in an electric field. And by following the

> path of that pole, you'd be able to see the direction of the lines... the initial direction of its motion would be a tangent... if it does have mass then its initial direction is the direction of the field at that point. So if you were to place it a little further along in that direction, but once again with no inertia so it's not already moving, then each place that you put it, it will move off in the direction of the magnetic field and so you could trace out a field line...

This student has stated the difference between field lines and particle trajectories, with some consideration of the effect of particle mass. The description of placing the particle "a little further along in that direction" seems to be a hint at infinitesimal reasoning, and is a way to describe this difference. In this context, it is mentioned that the filings, as little magnets, will form chains and align to the field. The response shows an overview of the question, though seems to lack conciseness. This conciseness would probably occur in a later cycle of growth.

CONCLUSION

The tertiary physics students studied generally had difficulty explaining the pattern in iron filings surrounding a magnet. There was a strong tendency for the students to reason in terms of a finite number of concrete lines to which the filings were attracted. This seemed to be their concept of 'field line' in the context of this phenomenon. The students' understandings of the specific phenomenon of patterns in iron filings around a magnet have implications for broader issues regarding student representation of magnetic and electric fields. Students generally did not use the idea of an abstract field vector associated with each point in space, preferring to answer in terms of concrete elements, and their ideas about field lines were accordingly excessively concrete. The common misconception that the field of the magnet had non-uniform 'lines' which attracted the iron filings to map them seems to be worthy of attention when teaching. Full understanding of the iron filing patterns and their relation to field lines requires quite a high level of understanding.

A hierarchy of levels of understanding of the phenomenon was found, within the Concrete Symbolic mode (levels 1a-1c above) and Formal mode (levels 2a-2c) of the SOLO Taxonomy, with one transitional level between the modes. The Formal mode was characterised by student use of an abstract model to explain the phenomenon involved, and a willingness to accept that the pattern seen was not simply a reflection of a finite number of concrete field lines.

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APPLICATION OF GENETICS KNOWLEDGE TO THE SOLUTION OF PEDIGREE PROBLEMS

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ABSTRACT

This paper reports on a study of undergraduate genetics students' conceptual and procedural knowledge and how that knowledge influences students' success in pedigree problem solving. Findings indicate that many students lack the knowledge needed to test hypotheses relating to X-linked modes of inheritance using either patterns of inheritance or genotypes. Case study data illustrate how these knowledge deficiencies acted as an impediment to correct and conclusive solutions of pedigree problems.

INTRODUCTION

Two of the most important factors influencing problem solving are the nature and demands of the task and the knowledge schemas brought to the task by the problem solver. In technical domains such as physics (Chi, Feltovich & Glaser, 1981), medical diagnosis (Elstein, Shulman & Sprafka, 1978) and genetics (Stewart, 1983), domain-specific knowledge and strategies have been shown to be critical for successful problem solving. Genetics is conceptually difficult (Finley, Stewart & Yarrock, 1982) and following instruction many students have been found to have significant misconceptions (Hackling & Treagust, 1984).

Pedigree problems that require students to identify the mode of inheritance of the trait are solved by a multiple hypothesis testing strategy (Hackling & Lawrence, 1988; Smith & Good, 1984). Hypotheses are tested using cues in the pedigree in the form of patterns of inheritance or by assigning genotypes to individuals in the pedigree. Experts have been shown to make greater use of cues and to conduct a more complete falsification of alternative hypotheses than novices (Hackling, 1990). Expertise is dependent on large, well-organized, domain-specific knowledge structures that facilitate the generation of high quality problem representations. In chess an extensive knowledge of chess board positions enables experts to select the best move in a given situation (Chase & Simon, 1973). Expert radiologists possess radiological anatomy knowledge schemas which enable them to interpret x-ray plate patterns in terms of variations in anatomical structures (Lesgold, 1982). Medical practitioners who failed to correctly diagnose a heart condition made errors in interpreting patient data cues that serve to generate or evaluate disease hypotheses (Johnson et al., 1981). Some errors in solving classical genetics problems have been traced to deficiencies in subjects' knowledge of meiosis (Stewart, 1983).

PURPOSE AND RESEARCH QUESTIONS

The purposes of this study were to assess the hypothesis-testing knowledge of undergraduate genetics students and to explore the effect of knowledge deficiencies on problem-solving performance. More specifically the study addressed the following research questions:

1. Are novice and advanced undergraduate genetics students and genetics lecturers able to correctly interpret a range of important pedigree cues?
2. Are novice and advanced undergraduate genetics students and genetics lecturers able to correctly assign genotypes to individuals in genetic pedigrees?
3. What effect do deficiencies in hypothesis testing knowledge have on pedigree problem solving performance?

METHOD

Procedure and subjects. Three subject groups worked through a pencil and paper test of hypothesis testing knowledge. Following the test, the advanced undergraduate students completed five pedigree problems with concurrent verbalisation of their problem solving processes. Think-aloud protocols were recorded on audio tape for analysis. The three subject groups were: five expert university genetics lecturers; an entire class of five advanced undergraduate university students who had completed three units of human genetics; and 219 novice undergraduate university students who had completed one unit that contained some human genetics.

The test. A pencil and paper test was used to assess the ability of subjects to interpret pedigree cues and to assign genotypes to individuals in pedigrees. In the first part of the instrument concise descriptions were used to illustrate the cues rather than pedigree diagrams. Pedigree diagrams were not used as they would provide additional information that might influence the interpretation of the cue. The instrument for novice students contained four important pedigree cues:

1. Two parents affected with the trait have an unaffected child.
   (The trait must be dominant)
2. A daughter affected with the trait has an unaffected father.
   (The trait can't be X-linked recessive)
3. A consanguineous mating of two unaffected parents produces a son affected with the trait. (The trait must be recessive)
4. A father affected with the trait has an unaffected daughter.
   (The trait can't be X-linked dominant)

In addition to these four cues the instrument for advanced students and genetics lecturers included three further cues:

5. Every affected child has at least one affected parent.
   (The trait is likely to be dominant)
6. Affected males are more common than affected females.
   (The trait is likely to be X-linked recessive)
7. A son inherits the trait from his father ie male-to-male transmission is present.
   (The trait can't be X-linked)

For each of the cues, subjects were asked to write a brief response to indicate the main thing that the cue told them about the mode of inheritance of the trait.

The second part of the instrument assessed subjects' ability to assign genotypes to individuals affected with an autosomal dominant trait in one pedigree and to individuals affected with an X-linked dominant trait in another pedigree. The two tasks were based on identical family trees but with different patterns of affected and unaffected individuals.

The pedigree problems. Each pedigree problem required the subjects to identify the mode of inheritance of the trait. Five problems were used and are described fully in Hackling (1990).

RESULTS

Results are reported for the three subject groups' interpretation of the cues and assignment of genotypes to individuals in pedigrees. This is followed by case study data that illustrate the effects of knowledge deficiencies on problem solving performance.

Interpretation of cues

Each of the cue interpretation tasks required subjects to write down the main thing the cue told them about the mode of inheritance of the trait. The proportion of subjects from the three groups that correctly interpreted the cues is presented in Table 1. Genetics lecturers were more successful than advanced students on all seven of the cue interpretation tasks. Genetics lecturers also were more successful than the novice students on all four cue interpretation tasks that were included in the novices' test instrument. Of the four cue tasks attempted by all groups, the cues relating to dominant and recessive traits were more often correctly interpreted by all groups than those relating to X-linked traits. Only 1% of novices correctly interpreted the X-linked recessive cue and only two percent of novices correctly interpreted the X-linked dominant cue. On Cues Five, Six and Seven, more of the advanced students correctly interpreted the dominant cue than the cues relating to X-linked recessive and X-linkage.

TABLE 1
PROPORTION OF THREE GROUPS CORRECTLY INTERPRETING PEDIGREE CUES

Cue	Correct interpretation	Proportion of correct responses		
		Genetics lecturers (n = 5)	Advanced students (n = 5)	Novice students (n = 201)
1	Trait must be dominant	0.80	0.60	0.32
2	Trait can't be XR[a]	0.60	0.00	0.01
3	Trait must be recessive	1.00	0.80	0.58
4	Trait can't be XD[b]	0.40	0.20	0.02
5	Trait likely to be dominant	0.80	0.60	
6	Trait likely to be XR	1.00	0.40	
7	Trait can't be X-linked	0.60	0.20	

Note: [a] X-linked recessive, [b] X-linked dominant

Several cue misinterpretations were quite common amongst novice students; 32% of them misinterpreted Cue One *two parents affected with the trait have an unaffected child* as indicating the trait must be recessive. Cue One is the mirror image of the cue that indicates recessive inheritance *two unaffected parents have an affected child*, hence novices may have failed to adequately distinguish between the two. For Cue 4, 15% misinterpreted *a father affected with the trait has an unaffected daughter* as indicating the trait must be recessive. These novices may have inferred a skipping of generations and hence the misinterpretation. A further 28% misinterpreted this cue as indicating the trait must be Y-linked. These novices may have gone beyond the information given and assumed that no females were affected which is characteristic of Y-linked traits. Cue Two *a daughter affected with the trait has an unaffected father* was misinterpreted as indicating the trait must be X-linked by 18% of novices. Many novices associate X-linked traits with patterns of inheritance where one gender is affected and the other is not. Data on novices' cue misinterpretations are presented in Table 2.

TABLE 2
PROPORTION OF 201 NOVICE STUDENTS MAKING COMMON MISINTERPRETATIONS OF CUES

Cue	Correct interpretation	Misinterpretation	Proportion of responses
1	must be dominant	must be recessive	0.32
2	can't be XR[a]	must be XL[c]	0.18
4	can't be XD[b]	must be YL[d]	0.28
4	can't be XD	must be recessive	0.15

Note: [a] X-linked recessive, [b] X-linked dominant, [c] X-linked, [d] Y-linked

Two cue misinterpretations were common amongst advanced students. Three out of five advanced students misinterpreted Cue Six *affected males are more common than affected females* as indicating X-linkage rather than specifically X-linked recessive. The over-generalisation of this cue to both forms of X-linked inheritance appears to be common amongst many students of genetics. Four out of five of advanced students interpreted Cue Seven *a son inherits the trait from his father* as supporting Y-linkage. This pattern is consistent with Y-linkage but to make a diagnosis of Y-linkage would also require all sons of affected father to be affected, all fathers of affected sons to be affected, and no females to be affected. In contrast, Cue Seven alone conclusively rules out both forms of X-linked inheritance.

Assignment of genotypes to individuals in a pedigree

Subjects were asked to assign autosomal dominant and X-linked dominant genotypes to identical pedigrees in the second part of the test instrument. The first pedigree showed which members of a family could taste phenylthiourea (PTC), an autosomal dominant trait. In this pedigree all males and females who could taste PTC were heterozygous and should have been assigned the genotype Tt or Pp. All males and females who could not taste PTC were homozygous recessive and should have been assigned the genotype tt or pp. If the subject used the correct combination of upper and lower case letters, any letter of the alphabet was accepted as a correct method of assigning genotypes.

The second pedigree showed which members of a family were affected with hypophosphatemic rickets, an X-linked dominant trait. Table 3 indicates the range of methods of indicating X-linked dominant genotypes that were considered acceptable for this task.

TABLE 3
ACCEPTABLE METHODS USED TO INDICATE X-LINKED DOMINANT GENOTYPES

	Method				
	1	2	3	4	5
Affected females (heterozygous)	$X^{R}X'$	Rr	Xx	X'X	Rr
Affected males	$X^{R}Y$	RY	XY	X'Y	R
Unaffected females	X'X'	rr	xx	X X	rr
Unaffected males	X'Y	rY	xY	X Y	r

Table 4 shows the proportion of the three groups who assigned genotypes which (a) used an incorrect method, or (b) used a correct method but did not assign an accurate genotype to every individual, or (c) used a correct method and assigned an accurate genotype to every individual in the pedigree.

TABLE 4
PROPORTION OF SUBJECTS USING AN INCORRECT METHOD, A CORRECT METHOD INACCURATELY, OR A CORRECT METHOD ACCURATELY TO ASSIGN AUTOSOMAL AND X-LINKED DOMINANT GENOTYPES

Groups	Proportion of subjects using:					
	Incorrect method		Correct method inaccurately		Correct method accurately	
	AD	XD	AD	XD	AD	XD
Genetics lecturers (n = 5)	0.00	0.00	0.00	0.00	1.00	1.00
Advanced students (n = 5)	0.20	0.20	0.00	0.20	0.80	0.60
Novice students (n = 201)	0.11	0.56	0.27	0.13	0.62	0.31

Novice students, advanced students and genetics lecturers demonstrated successively higher levels of performance on the genotypes tasks. None of the genetics lecturers made any errors in assigning autosomal dominant (AD) or X-linked dominant (XD) genotypes. Both student groups were more successful in assigning AD genotypes than XD genotypes. When assigning XD genotypes, 56% of novices used an incorrect method, the most common error being to assign two alleles for the trait to the hemizygous males.

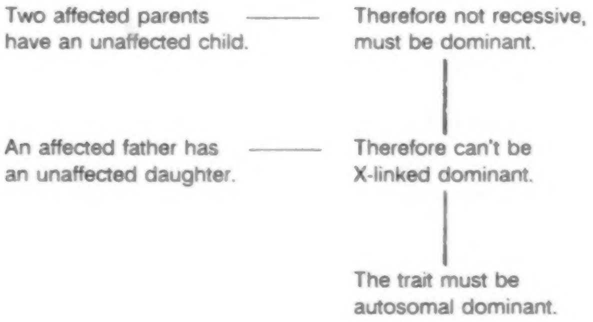
Case study data

Subject One identified the correct mode of inheritance for Problems A (autosomal dominant), B (autosomal recessive) and D (X-linked recessive) but not for problems C (X-linked dominant) or E (autosomal dominant and sex limited or autosomal dominant with incomplete penetrance). On the written test no cues related to X-linkage were correctly interpreted and the subject was not able to correctly assign autosomal or X-linked dominant genotypes. Only two cues were interpreted correctly on the written test, Cue Three, *a consanguineous mating of two unaffected parents produces a son affected with the trait* ie the trait must be recessive and Cue Four *every affected child has at least one affected parent ie the trait is likely to be dominant*. These two cues could be used to distinguish between dominant and recessive modes of inheritance.

Subject One commenced each pedigree problem by verbally listing the affecteds and unaffecteds in the pedigree working from the first generation downwards until she recognized a cue. Once that cue was dealt with the subject recommenced listing down through the pedigree until another cue was recognized. On all problems Subject One used two pedigree cues. The first was used to discriminate between dominant and recessive, and the second was used to distinguish between autosomal and X-linked modes of inheritance. The first cue was whether affected individuals were found in every generation (correctly interpreted as supporting dominant) or if the trait skipped a generation (correctly interpreted as supporting recessive). The second cue was whether males and females were affected, or only males were affected with the trait. If some females were affected this was misinterpreted as ruling out X-linkage. If only males were affected this was misinterpreted as supporting X-linkage rather than specifically X-linked recessive inheritance. The subject's lack of understanding of X-linkage as demonstrated by her failure to correctly interpret any of the X-linkage cues on the written test (Cues Two, Four, Six and Seven) explains her inability to recognize and use important X-linkage cues when solving the pedigree problems.

Subject One's problem solutions were either incorrect or inconclusive. A comparison of the solutions generated by expert consensus (Figs. 1a and 2a) with Subject One's solutions to Problems A and C (Figs. 1b and 2b) illustrate how the absence of knowledge regarding X-linked modes of inheritance has acted as an impediment to correct and conclusive problem solutions. Fig. 1 illustrates the solution paths for Problem A produced by expert consensus and by Subject One.

(a) A Complete and Conclusive Solution of Problem A as Determined by Expert Consensus


Two affected parents
have an unaffected child.
Therefore not recessive,
must be dominant.
An affected father has
an unaffected daughter.
Therefore can't be
X-linked dominant.
The trait must be
autosomal dominant.

(b) Subject One's Solution of Problem A

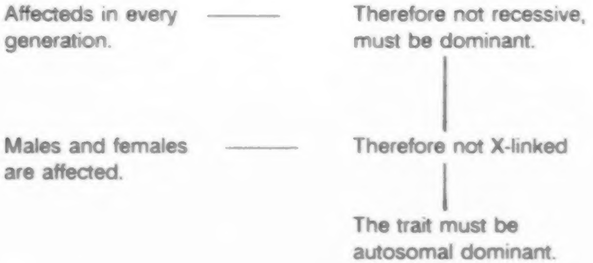

Affecteds in every
generation.
Therefore not recessive,
must be dominant.
Males and females
are affected.
Therefore not X-linked
The trait must be
autosomal dominant.

Fig. 1 Solution routes for Problem A: (a) Expert consensus; (b) Subject One

Both solutions initially rule out recessive modes of inheritance using a cue. The cue used by the experts (*two affected parents have an unaffected child*) conclusively ruled out recessive inheritance whereas the cue used by Subject One (*affecteds in every generation*) only indicated that recessive inheritance is unlikely. The second cue used by the experts (*an affected father has an unaffected daughter*) conclusively ruled out X-linked dominant whereas the cue used by Subject One (*males and females are affected*) provided no evidence about this mode of inheritance. Subject One did identify the correct mode of inheritance but the solution was far from being complete or conclusive.

Fig. 2 illustrates the solution paths for Problem C produced by expert consensus and by Subject One. The experts' solution is based on the recognition and interpretation of five cues. Initially cues are used to rule out the two recessive modes of inheritance and then provide support for dominant inheritance. Two further cues are then used to weaken the autosomal dominant hypothesis and support the X-linked dominant hypothesis. X-linked dominant is then identified as the most likely mode of inheritance of the trait. The answer cannot be given with certainty as all of the alternative modes of inheritance cannot be ruled out beyond all doubt. Subject One's solution is based on two cues, the first of which (*some females are affected*) is

(a) A Complete and Conclusive Solution to Problem C as Determined by Expert Consensus

An affected daughter has an unaffected father	Therefore can't be X-linked recessive.
Autosomal recessive requires five unrelated carriers of the rare trait	Therefore highly unlikely to be autosomal recessive
All affected children have at least one affected parent.	Therefore likely to be dominant.
Of 19 children from affected fathers only daughters are affected.	Therefore highly unlikely to be autosomal dominant.
All daughters but no sons of affected fathers are affected.	Therefore likely to be X-linked dominant.
	The trait is probably X-linked dominant.

(b) Subject One's Solution of Problem C

Some females are affected	Therefore it's not X-linked.
It occurs in every generation.	Therefore it's dominant.
	The trait must be autosomal dominant.

Fig. 2 Solution Routes for Problem C :(a) Expert consensus; (b) Subject One.

misinterpreted as ruling out X-linkage. The subject failed to identify the correct mode of inheritance because she lacked the knowledge of X-linkage necessary to identify the cues which indicated that the trait was more likely to be X-linked dominant than autosomal dominant.

DISCUSSION

The domain specific conceptual and procedural knowledge of experts is organized into schemas which correspond to categories of problems within their area of expertise (Chi et al., 1981). Geneticists' knowledge is assumed to be organized into schemas that correspond to particular modes of inheritance. To account adequately for the problem solving behaviour of expert geneticists the schemas would have to contain information about the pedigree cues that are associated with that mode of inheritance, the rules used to interpret the cues, and the operations needed to assign genotypes consistent with that mode of inheritance to individuals in pedigrees.

To interpret pedigree cues the subject is required to identify the critical elements of the cue and attempt to find a match with the cues held in the various schemas. If sufficient matching of critical elements in the cue and schema occurs the schema is activated and the cue interpretation rules in the schema are available to interpret the cue in terms of that particular mode of inheritance. The cue interpretation rules may be in the form of production rules comprised of condition action pairs as proposed by Smith (1986). The condition side of the rule defines the critical elements of the cue, whereas the action side of the rule provides the interpretation of that cue in terms of the mode of inheritance.

When asked to provide an interpretation of Cues Two and Four which are related to X-linked recessive and X-linked dominant modes of inheritance, only 1% of novices were successful on Cue Two and only 2% were successful on Cue Four. How can these events be explained in terms of deficiencies in novices' inheritance schemas? Failure to provide a cue interpretation may result from the subject having failed to develop a schema for the relevant mode of inheritance, the relevant schemas may exist but the relevant cue interpretation rules may be absent, or the rule may have the appropriate condition but lack the corresponding action component. Cue misinterpretation may result from a rule comprised of an inappropriate pairing of condition and action, or failure to accurately discriminate the critical elements of the cue may result in matching the cue to an inappropriate schema.

The correct method of assigning autosomal dominant genotypes was used by 89% of novices, although only 62% assigned a correct genotype to every individual in the pedigree. Of greater concern was the low success rate of novices in assigning X-linked dominant genotypes. Only 44% of novices used an acceptable method, and only 21% assigned a correct genotype to every individual in the pedigree. The use of any of the acceptable methods of assigning X-linked dominant genotypes presented in Table 3 requires an understanding of the locus of genes on the X and Y chromosomes resulting in males carrying only one allele for X-linked genes. Most of the 56% of novices who did not use an acceptable method of assigning X-linked dominant genotypes assigned a pair of alleles to the males in the pedigree. This lack of understanding of the basic mechanisms of X-linked inheritance must also limit novices ability to interpret pedigree cues associated with X-linkage such as Cues Two and Four, and as a consequence be limited in their ability to adequately test inheritance hypotheses involving X-linkage.

The case study data presented for Subject One illustrate the importance of knowledge of X-linkage cues for producing correct and conclusive solutions to pedigree problems. The inconclusive solution to Problem A and the incorrect solution to Problem C produced by

Subject One have been directly traced to a failure to recognize and correctly interpret X-linkage cues.

CONCLUSIONS

In this study novice students, advanced students and genetics lecturers demonstrated successively higher levels of knowledge for testing inheritance hypotheses by cue interpretation and assigning genotypes. In solving pedigree problems there is a need to distinguish between dominant and recessive, and between autosomal and X-linked modes of inheritance. This study has shown that most of the novice students lack the knowledge needed to adequately test X-linked modes of inheritance using either cues or genotypes. This limited knowledge of X-linkage has been shown to be a significant impediment to correct and conclusive solutions of pedigree problems.

Hackling and Lawrence (1988) have demonstrated that the strategy of falsifying alternative hypotheses is also a requirement for pedigree problem solving success. Effective pedigree problem solving is therefore dependent on critical hypothesis testing knowledge used in combination with the general problem solving strategy of multiple hypothesis testing with rigorous falsification of alternative hypotheses.

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STUDENT BELIEFS AND LEARNING ENVIRONMENTS: DEVELOPING A SURVEY OF FACTORS RELATED TO CONCEPTUAL CHANGE.

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ABSTRACT

This paper presents a model for the type of classroom environment believed to facilitate scientific conceptual change. A survey based on this model contains items about students' motivational beliefs, their study approach and their perceptions of their teacher's actions and learning goal orientation. Results obtained from factor analyses, correlations and analyses of variance, based on responses from 113 students, suggest that an empowering interpersonal teacher-student relationship is related to a deep approach to learning, a positive attitude to science, and positive self-efficacy beliefs, and may be increased by a constructivist approach to teaching.

INTRODUCTION

Ever since the problem of alternative frameworks became a live issue in the science education community, researchers have been asking the question: How can teachers help students learn science so that they integrate new science learning into the conceptual frameworks they use in everyday life? A rational constructivist or generative approach (Posner, Strike, Hewson & Gertzog, 1982; Cosgrove & Osborne, 1985), especially with an emphasis on 'metalearning' (White & Gunstone, 1989) has gone a long way towards solving the problem. But this "cold," rational approach (Pintrich, Marx & Boyle, 1993) depends on students becoming deeply cognitively engaged and does not necessarily manage the affective aspects of learning.

Pintrich et al. (1993) proposed a model of conceptual change learning. It linked the types of tasks set, the authority structures, the evaluation structures, classroom management, teacher modelling and teacher scaffolding with motivational and cognitive factors considered necessary for the conditions Posner et al. (1982) proposed as prerequisites for conceptual change (dissatisfaction with prior conceptions, and new conceptions being seen as intelligible, plausible and fruitful). Pintrich et al. claimed that these classroom factors all influenced the quality of learning by modifying students' expectancy and value beliefs. Many other education researchers have found results consistent with this model but some have added new features or new emphases.

The conceptual change learning environment

I am proposing a new explanatory model of an ideal conceptual change learning environment which relates teacher actions to implied teacher beliefs and likely related student beliefs and actions (see Table 1). The 'Teacher Actions' column lists the characteristics of learning environments which have been found by many recent researchers (see below) to have the most effect on cognitive and motivational factors believed to enhance a deep approach to learning. In general, these classrooms, take a constructivist approach to learning and are more likely to be student-centred with a mastery (as opposed to a 'work') goal orientation (Ames & Archer, 1985; Roth et al., 1992). Teachers in these learning environments are more likely to allow students to assume responsibility progressively for their own learning, and are more likely to provide opportunities for regular student reflection on thinking and learning (Collins, Brown & Newman, 1989; Blumenfeld, Mergendoller & Puro, 1992; Roth et al., 1992).

TABLE 1

ENCULTURATION MODEL FOR AN IDEAL LEARNING ENVIRONMENT, RELATING TEACHER AND STUDENT ACTIONS TO PROJECTED STUDENT BELIEFS

TEACHER ACTIONS	INTERVENING STUDENT BELIEFS		STUDENT ACTIONS
	IMPLICIT MESSAGE	SELF-TALK	
	Related to Learning		
Activating prior learning and personal involvement; setting authentic tasks; asking questions about understanding; elaborating on new concepts; getting students to plan, carry out and evaluate activities; treating mistakes as positive; providing a safe environment for risk-taking; sharing control of learning and talking about learning.	Student understanding takes priority; new learning must be accommodated into prior learning which takes time and a cooperative setting; learning and motivation are related; student autonomy, learning to learn, broad goals for learning are all important.	Learning science is about working out my own ideas about the world, and it takes time. Science is about explaining and justifying ideas to others. My learning is under my control, and learning how to learn is part of successful learning. Science is about life.	Admitting and dealing with conceptual conflict; persisting with difficult new learning; seeing practical work as testing ideas; reflecting on and discussing ideas; self-regulating own learning; taking risks.
	Related to Students		
Encouraging participation by all students, and listening attentively to them; communicating warmth, empathy and enthusiasm; exercising control with empathy; using small and large group discussion.	All students have ability; they and their ideas are worthy of respect; everyone is an important part of the group.	I have the ability to understand science. My ideas count. I am a worthwhile person whose concerns will be respected. I need not fear humiliation here.	Becoming engaged in activities; asking and answering questions; persisting with tasks; speaking and listening in group discussion.
	Related to Teacher Dependence		
Structuring tasks and using modelling to equip students to progress towards independence; guiding students' thinking for tasks they find difficult; facilitating interaction between students.	When tasks have been well explained and modelled, students can complete higher as well as lower order tasks successfully, with a minimum of teacher help.	I/Our group can do science without relying too much on the teacher. The tasks are challenging but achievable.	Undertaking given tasks willingly, reporting more scientific self-efficacy, and more positive attitudes towards science.

Just as importantly, such conceptual change learning environments are seen as being more likely to provide socio-emotional support in a "non-threatening learning environment" (Watts & Bentley, 1987), and motivational beliefs are usually seen as being crucial rather than peripheral (Pintrich et al., 1993; Roth et al., 1992). Consequently each student's learning is respected and serves to contribute to the more communal construction of meaning. In this way new learning is framed in a larger context which is culturally meaningful to the student (Blumenfeld et al., 1992; Collins et al., 1989; Roth et al., 1992).

Learning environments, however, are not merely the sum of teacher behaviours. Rather, they are a dynamic interaction between the teacher and students, based on their interpretations of each other's actions. Thus the beliefs assumed to underlie these actions are a necessary part of a model linking teacher actions to student learning (see Table 1).

Teacher and student actions associated with conceptual change. A brief summary of the findings relating to teacher actions is presented in the first column of Table 1 and student actions believed to be related to them are presented in the last column. These actions are grouped according to whether they are believed to affect students' beliefs about learning, their beliefs about themselves as students, or their beliefs about how much they need to depend on the teacher. However, since research on student learning suggests that it is not teacher behaviours per se that affect the students' actions but rather how students **interpret** them (Wittrock, 1986/1990), two columns have been added to explain student interpretations which might explain how the teacher actions influence the student actions.

Student beliefs associated with conceptual change. Congruent teacher beliefs may be crucial to the success of particular teaching methods, perhaps because of the implicit messages conveyed by the totality of a teacher's actions (Combs, 1984). When implicit and explicit messages are in conflict, implicit messages may have more impact than explicit messages (Argyle, 1975). Hence such messages are thought to be important and the second column of Table 1 suggests teacher beliefs that students may infer from their observations of teacher actions.

Intervening between the implicit (teacher) messages column and the student actions column is a column presenting student beliefs--their beliefs about learning, their beliefs about themselves and their beliefs about the domain. It is suggested that these motivational beliefs may be influenced by or at least be reinforced by their interpretations of teacher behaviour (i.e., the implicit messages) and consequently may mediate student actions.

Investigating the relationship between student beliefs and the learning environment

The various relationships asserted here between motivational beliefs, cognitive engagement and learning environment factors have all been recorded previously in one form or another in a range of domains. Various methods have been used to investigate them, including generalised questionnaires (Ames & Archer, 1988; Blumenfeld et al., 1992; Grolnick & Ryan, 1987; Pintrich et al., 1993).

When factor analysed, questionnaires or surveys can provide indications of constructs which tend to be significant in the conceptual frameworks of a group of respondents, by grouping items which tend to be correlated for the individuals within the group. Responses to items on questionnaires--and therefore the resultant factors--are most likely to be meaningful when directed at a specific rather than a general context. Hence the relationship between factors believed to be important for conceptual change learning in science will be easiest to interpret with a scale specific to the science classroom.

Why a new science learning environment scale?

As part of an in-depth study of the interrelationships between the science learning environment, students' motivational beliefs and their level of cognitive engagement, I wanted to administer a personalised learning environment questionnaire. I wanted it to include items to measure perceptions of all three factors, and particularly to include items designed to measure the extent to which students perceived that they were encouraged to believe personal understanding was important, and the extent to which it was safe to express their own ideas. Current learning environment scales designed to measure student perceptions of teacher interpersonal behaviour, such as the Questionnaire of Teacher Interaction (Wubbels, 1993) and some scales of the Individualised Classroom Environment Questionnaire (Fraser, 1990), did not meet these specific requirements.

On the other hand, critical constructivist learning environment scales, such as the Classroom Environment Survey (Tobin, 1993), and the Revised Constructivist Learning Environment Survey (Rev. CLES; Taylor, Fraser & White, 1994), which did deal with constructivist issues and empowerment, did not explicitly address the interpersonal relationship between the teacher and student. What was needed was a new scale which included items designed to measure students' interpretations of the relevant interpersonal factors, their interpretations of other constructivist learning environment factors, and their perceptions of their own learning approach. The relevant a priori categories which did not seem to have a significant place in other surveys included the perceived learning goal orientation of the class, the epistemological beliefs of the students, and students' perceptions of teacher support for autonomy, of their own personal empowerment, of the level of their cognitive engagement, and of the level of challenge of tasks set.

METHOD

Subjects

Respondents were 113 students from six science practical workshop groups of a typical primary teaching preservice class at a Queensland University. The students participated voluntarily in the research. (See Watters, Ginns, Neumann & Schweitzer, 1994, for more details of the larger research project on self-efficacy in which this study was situated.)

Procedure

All groups completed the following three surveys at the end of the semester in their final practical class. The **Survey of Apparent Learning Goal Orientation** (SALGO) was developed to be used as a survey measure with this particular class, from items based on the conceptual change environment model as represented in Table 1, but leaving out items which were conceptually similar to those in scales being measured by the Revised CLES which was being administered on the same occasion (see below). The three cognitive engagement items were adapted from the Science Activity Survey (Meece, Blumenfeld & Hoyle, 1988). For this initial trial, SALGO was limited to 20 items by time constraints and was scored using a five-point Likert type scale of agreement-disagreement. The **Revised Constructivist Learning Environment Scale** (Rev. CLES--Science) included five scales, and an added attitude scale (Taylor et al., 1994). It had 42 items in all and a five-point Likert type frequency scale. The **Science Teacher Efficacy Belief Instrument** (STEBI-B, Riggs & Enochs, 1990) had two scales, a personal science teaching efficacy scale and a science teaching outcome expectancy scale. It consisted of 23 items, and was scored on a five-point Likert scale of agreement-disagreement.

RESULTS AND DISCUSSION

Factor analysis

Factorability of the data. Factorability of the correlation matrix for the SALGO was found to be highly satisfactory (Kaiser-Meyer-Olkin measure of sampling = 0.82, Bartlett's test of sphericity significant at $p< =0.00001$).

Choice of factor solution. On the basis of the size of the eigenvalues obtained as part of an initial run using principal components extraction, a six factor solution was the first solution considered, since there were six factors with an eigenvalue greater than one. However the scree test (Cattell, 1966, cited in Tabachnick & Fidell, 1989) produced by this initial run indicated that a single factor solution should also be considered, since there was a noticeable drop in size of eigenvalues between the first and second factor and the rest could reasonably have been interpreted as a scree.

With **the single factor solution**, the single factor accounted for 26.7% of the variance. All variables loaded on it (the lowest correlation at $r = 0.28$). Since it included all of the a priori factors, it was labelled a Conceptual Change Learning Environment factor. (The positive pole seemed to represent the kind of features Roth et al., 1992, describe as "a conceptual change science learning community", and the negative pole those of the "work-oriented classroom".) Since it was composed of functionally different items, the six-factor solution was examined to see whether meaningful subscales would emerge.

TABLE 2

DESCRIPTIVE INFORMATION FOR THE SCALES ON THE SURVEY OF APPARENT LEARNING GOAL ORIENTATION

SCALE NAME	DESCRIPTION	SAMPLE ITEMS	ALPHA
PERSONAL EMPOWERMENT (5 items)	The extent to which the teacher in this class is perceived as showing regard for the student.	• In this class the teacher would rather you gave the approved answer than say what you really think. (-)	0.78
TEACHER SUPPORT FOR AUTONOMY IN THINKING (4 items)	Extent to which the student feels free to express personal thinking about scientific concepts.	• Our teacher sometimes gets our class to discuss whether an answer seems reasonable to us or not.	0.72
DEEP APPROACH TO LEARNING (4 items)	Extent to which student believes he/ she must actively construct own knowledge.	• Learning science is about working out my own ideas.	0.73

Note. (-) means the item was reverse coded.

The **six-factor solution** accounted for 48.4% of the variability and, using a cut-off of 0.4, accounted for all of the items. When loadings of greater than 0.4 were taken into account a relatively simple structure was evident. The first three factors were reduced to items which remained stable over different rotations, and alpha reliability values for these were 0.78, 0.72 and 0.73, respectively, which was satisfactory especially given the low number of items of each factor (5, 4 and 4 respectively). The remaining factors, although interpretable, had too few intercorrelated items to be reliable, and were disregarded for purposes of interpretation in this case. The factors were clearly interpretable, and the following factors or scales are therefore proposed and sample items are presented in Table 2). The first factor clearly represented **Personal Empowerment** (PE), the extent to which the student believed the teacher treated him or her with respect as a person and would not to take advantage of the power differential inherent in the class situation to coerce or humiliate the student. The second factor would seem to represent **Teacher Support for Autonomy in Thinking** (TSAT) or the extent to which the student believed he or she had permission in this class to formulate and express personal understandings of scientific concepts. The third factor combines epistemological belief items with cognitive engagement items to represent a **Deep Approach to Learning**.

Construct validity

Since one of the original purposes of the construction of the SALGO was to investigate factors believed to be an important part of a successful constructivist learning environment but which had little place in existing constructivist learning environment scales, (unweighted) factor scores were used to determine intercorrelations among scales and correlations with other variables measured (Table 3).

TABLE 3
CORRELATIONS: SALGO SUB-SCALES WITH OTHER FACTORS

	PE^1	TSAT^1	DAL^1
Teacher Support for Autonomy in Thinking	0.56***	1.00	0.49***
Deep Approach to Learning	0.56***	0.49***	1.00
Revised CLES			
Personal Relevance	0.33***	0.40***	0.32**
Scientific Uncertainty	0.23*	0.23*	0.33***
Critical Voice	0.32***	0.41***	0.26**
Shared Control	0.08	0.41***	0.09
Student Negotiation	0.45***	0.47***	0.33***
Attitude to Science	0.44***	0.40***	0.45***
STEBI-B (Self-Efficacy)			
Personal Science Teaching	0.36***	0.22*	0.41***
Science Teaching Outcome	0.31**	0.32**	0.23*

PE = Personal Empowerment; TSAT = Teacher Support for Autonomy in Thinking; DAL = Deep Approach to Learning. * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$.

The SALGO scales had only moderate intercorrelations with each other and so are usefully considered as separate factors. The CLES scales were related to the three SALGO scales but at approximately the same low to moderate level of correlations as they had among themselves (0.20 - 0.55), which demonstrates that the two sets of learning environment factors together contain eight related but distinct factors, as they presented in this context.

All three SALGO scales also had moderate correlations with the CLES science attitude scale, which is notable since anything that may improve students' attitudes to learning science is of interest; and low to moderate correlations with the self-efficacy measures, which is not so surprising, since the course was not directly related to the efficacy measure (the course was a science foundations course, and the self-efficacy was related to teaching science).

Criterion validity of the scales

While the Revised CLES (Taylor et al., 1994) and the CES (Tobin, 1993) included autonomy, relevance, shared control, or critical voice scales which imply student empowerment, they place much less emphasis on the permission the student perceives he or she has to think about or express his or her ideas about science concepts, which implies empowerment at a more personal level. One would suppose that students would need to feel empowered at this personal level before they would even contemplate sharing control of learning at the curricular level. It was proposed, therefore, that SALGO's Personal Empowerment, Teacher Support for Autonomy in Thinking or Deep Approach to Learning might differentiate between class groups differing in whether or not a constructivist teaching approach was used, where a more radical scale might not.

Consequently an analysis of variance for the SALGO factors was done with the teaching approach as the unit of analysis (Table 4). The first workshop group had been taught according to a constructivist approach (the teacher explicitly helped students to consider their prior knowledge and relate new learning to it and involved them in discussion and personal writing about their understanding of the concepts and the usefulness of the practical activities) and the other five groups were taught by different teachers in a more traditional method (lecturing, practical activities, and assessment of a formal practical report). Nevertheless, teachers in all workshops were required to teach the same topics and complete the same practical activities.

TABLE 4
ANOVA RESULTS FOR TEACHING APPROACH GROUP DIFFERENCES IN STUDENT PERCEPTIONS OF CLASSROOM ENVIRONMENT

SALGO Scale	MS Between	MS Within	df	F	Eta^2
PERSONAL EMPOWERMENT	10.04	0.33	1, 111	30.65 $p<0.001$	0.22
TEACHER SUPPORT FOR AUTONOMY IN THINKING	3.98	0.29	1, 111	13.95 $p<0.001$	0.11
DEEP APPROACH TO LEARNING	1.60	0.26	1, 111	6.07 $p<0.05$	0.05

Using SPSS ANOVA, significant differences at the 0.05 level were found between the first workshop group (constructivist approach) and all the other workshop groups combined (non-constructivist approach) for all three scales, Personal Empowerment (PE; $p < 0.001$), Teacher Support for Autonomy in Thinking (TSAT; $p < 0.001$), and Deep Approach to Learning (DAL; $p = 0.015$). That there was not a larger difference for DAL is at first surprising since this factor would seem to be the most closely related to a constructivist approach, but when one considers that DAL consists of beliefs and behaviours that are likely to be deeply rooted and of long standing, it is note-worthy that there is a significant difference at all for the two teaching approach groups. Similar analyses of variance were also performed using the students' scores on each of the Revised CLES scales, including the attitude scale, and on the

STEBI-B (self-efficacy) scales, without any significant differences being found between any of the groups. Thus the hypothesis that the SALGO scales would differentiate between these teaching approaches, where a more radical scale might not, was confirmed. (Further results, and copies of the Salgo questionnaire and proposed scales with item loadings, are available from the author on request.)

The differences found between the constructivist and the more traditional workshop groups gives some support to the validity of the SALGO scales as measures of a constructivist learning environment. The PE and TSAT scales may be especially useful for teachers who are attempting to assist their students to take back control of their own learning, and the Deep Learning Approach scale may be a useful aid to teachers wanting to gauge the epistemological beliefs and level of cognitive engagement of their students.

These results, however, should be treated with caution for two reasons. Firstly, since the measures were only used at the end of the semester, there is no guarantee that the randomly allocated groups (in as far as students in University courses can be randomly allocated) did not differ significantly before they experienced the different learning environments. Secondly, since the workshops differed in both teacher and students, it is impossible to know which out of many possible factors and interactions between factors influenced these results. Consequently a more in-depth study would be needed to investigate why the students responded as they did on the SALGO questionnaire, and what part a constructivist approach played in the overall result.

CONCLUSION

This study reported on an evaluation of a model which proposed interrelationships between the quality of student learning, students' motivational beliefs and the science learning environment as interpreted by students. A personalised constructivist learning environment scale, the Survey of Apparent Learning Goal Orientation, was constructed based on this model and would seem to be a useful instrument for measuring some factors which may be related to conceptual change. As such it could be a useful adjunct to other science learning environment scales.

Results obtained using the SALGO would seem to indicate that students' beliefs and actions may be affected by their interpretations of the teacher's actions. A relationship was reported between perceptions of the teacher as treating students and their thinking with respect, of the teacher as encouraging student discussion of scientific ideas, and of themselves as having a deep approach to learning. These dimensions also correlated with other critical constructivist learning environment factors, attitudes to learning science, and self-efficacy measures.

Moreover, the fact that such perceptions differed significantly between groups, suggests that these perceptions are not solely the result of relatively stable personality characteristics but may be influenced by the learning environment. There is some evidence that a learning environment which has an explicitly constructivist approach to teaching may be more likely to be perceived by the students as having a teacher who respects them, and who supports autonomy in thinking, as well as to be a place where they are more likely to take a deeper approach to learning.

From a methodological perspective, although the first three SALGO factors were reliable and appear to be conceptually valid in this context, the SALGO as a whole needs fuller development and further testing with a larger pool of items and a more substantial and diverse population if it is to be used as a survey instrument with more general applicability. It must be remembered that, because of time constraints, the initial item pool on this short trial version of the SALGO was only 20 items, with only three or four in each of the a priori categories. Consequently, with an increased number of items, it is possible that even stronger factors would be found, and that, with classes differing in the activities set, the factors disregarded in this study (such as the level of challenge of tasks) could still prove to be reliable factors.

In any case, regardless of the statistical tests of significance for factors, the meaning (or meanings) of the items to students, and their relationship to the subculture of the classroom as it continually evolves, needs to be investigated in more depth before more confident assertions about relationships in a particular context can be made (Taylor et al., 1994; Tobin & McRobbie, 1994, in a paper submitted to Science Education). A preferable method of using the SALGO would be to adapt it for the particular context a researcher is interested in investigating, by choosing items that are theoretically similar but more relevant in that context.

Nevertheless, it seems that factors which influence students' motivational beliefs may be just as important to conceptual change as coldly rational factors relating strictly to content. How students perceive the teacher behaving towards them may influence the depth of their cognitive engagement and thus the quality of their learning. Teachers who want students to learn with more than superficial understanding may need to communicate to their students a mastery learning goal orientation and respect for their students' learning capabilities. It also seems prudent to add, however, that one should not expect big changes to happen quickly in such relatively stable characteristics as epistemological beliefs and learning approaches. Positive learning beliefs and actions probably need to be nourished by the learning environment over a considerable period of time, before they change substantially.

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SUBJECT COMPETENCY OF TEACHERS AND LEVEL OF DEPENDENCE ON RESOURCE PACKS TO TEACH LEVERS, GEARS AND PULLEYS

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ABSTRACT

This pilot study set out to ascertain whether the level of dependence on resource material is related to teaching experience, existing understanding in mechanics, and perceived self confidence in science and technology. Details of teaching experience and qualifications were obtained from 11 experienced teachers and 10 initial teacher trainees, and understanding of mechanics was assessed by a written test. Each teacher worked through one commercially produced inservice pack about levers, pulleys or gears, and then prepared a 30 minute session for 4 ten year old children. Videos of the sessions were analysed with respect to the extent to which the pack was the sole focus; the amount of integration with other teaching aids and approaches; and the extent individual children's needs were satisfied. Although science qualifications influenced teacher confidence, they were not accurate predictors of relevant knowledge and teaching competence. As the majority of teachers followed pack instructions closely, the children's needs were not always well matched.

INTRODUCTION

Until recently, science was rarely included in the primary curriculum of British schools, and what was taught mainly consisted of natural rather than physical science. However the introduction of a National Curriculum requires both biological and physical sciences to be taught. As primary teachers have not been expected to have science qualifications and many have not had much, if any, training in science during their initial teacher training, they lack confidence to teach science, particularly the physical aspects. It is important therefore to assist these teachers to improve their confidence and competence in teaching primary science.

Lack of primary teachers' self-reported confidence and competence to teach science is well documented (Wragg, Bennett & Carre, 1989; Barnes & Shinn-Taylor, 1988). Barnes et al. (1988) obtained ratings of how competent and confident teachers felt in teaching specified curriculum areas. While teachers felt highly competent in English and maths, they perceived themselves to have low levels of competence for teaching science. Most of the teachers concerned did, however, wish to retain the teaching of science to their own class but with active assistance. One anecdote reported by Barnes describes a teacher who wished to go on a course but was constrained by lack of supply cover, or by tiredness at the end of the day. One possible answer to this problem may be the distance-learning pack and several developments are under way to provide such packs but progress is slow and there are problems of effectiveness with this method.

There is currently a limited amount of written or physical resources, such as work schemes and activity packs, available to support primary teachers in science and there has been little evaluation of their value. Newton (1992) points to evidence that the use of published support material helps teachers provide activities which allow a wider range of skills to be practised. However, the North East survey (Barnes et al., 1988) suggests that commercial schemes are not the full answer, as many of those available suggested experiments and areas for exploration which had proved to be counter-productive for teacher confidence, reinforcing teachers' feeling of their own lack of scientific knowledge. The Thomas Report (1985) called for the publication of science guide lines and other support materials (para 2.165) and hoped there would be advice on schemes and suitable content to promote continuity over the school years. This paper reports on teachers use of one activity pack with the intention of informing this debate.

There is also the issue whether all new primary teachers should have a qualification in science, as is already required for mathematics and English. McDiarmid, Ball and Anderson (1988) cite evidence that teachers' subject knowledge is crucial if they are to be effective in making curricular decisions, selecting tasks, posing questions and evaluating pupils' understanding. However, in a study in Israel, Rich (1993) found that although subject matter proficiency contributes to, it is not the sole determinant of expert teacher performance in unfamiliar pedagogical situations. The Association for Science Education (1992) stated that "The curriculum can only be what the teacher and learners make of it...Teachers rely on a knowledge, and understanding of the learning process and not on the learning matter, although a teacher's knowledge about what is taught is usually a pre-requisite." Consequently if knowledge is only obtained through science academic qualifications it may be inadequate for effective teaching. Newton (1992) suggests that some teachers who are science graduates fail to point out the relevance of science in the real world or link it to the everyday experiences of the child. The STAR project found that some teachers who felt they did not know how to plan or teach science avoided teaching concepts while others adopted a didactic approach, transmitting specific facts with little if any discussion in which the teacher's own understanding might be challenged (Cavendish, Galton, Hargreaves & Harlen, 1990; Russell & Harlen, 1990; Schilling, Harlen, Hargreaves & Russell, 1990). Therefore, in addition to investigating the use of support material, this paper also explores the relationship between teachers' qualifications and their competence to teach primary science.

This pilot study used three commercially produced inservice packs focused on levers, pulleys or gears to ascertain

- the approaches adopted by teachers to use resource materials with primary children;
- whether the level of dependence on resource material was related to teaching experience, existing understanding of mechanics, and perceived self confidence in science and technology; and
- to what extent teachers' confidence and competence to teach mechanics to primary children was related to their qualifications in subjects with high physics content.

METHOD

Sample

The project involved ten initial teacher trainees enrolled in a junior specialist postgraduate course, and eleven experienced primary teachers on in-service primary science and primary technology courses, during the 1993-94 academic year. Their participation occurred before their courses had covered work on energy and mechanics.

Questionnaire about qualifications and teaching confidence

Each participant completed a questionnaire about their science qualifications and previous relevant work experience, such as laboratory work. They were also asked to respond to two activities to ascertain their attitude towards teaching science in general. The first exercise asked them to underline the words which described how they felt about teaching science to ten year old children. The teachers could choose from the following words which were randomly placed on the page:

> Negative: petrified, panic, nervous, incapable, apprehensive,
> Neutral: unconcerned, calm,
> Positive: happy, stimulated, enthusiastic, knowledgeable, confident

The second task required the participants to rate their own confidence about teaching several curriculum subjects to nine and ten year olds. They were asked to respond on a 5-point scale which ranged from no confidence to very confident. The subjects covered included music, IT, physical education, mathematics, science, history, geography, technology, drama and English.

Exercise to assess concept understanding

Understanding of the aspects of mechanics covered by the packs was assessed by a second written exercise. The questions included asking for the teachers ideas about forces and energy; a definition of a machine; and an explanation of 'gearing up and gearing down'. The participants were also asked to write down what they understood about the words lever, pulley, gear, pivot, fulcrum, axle, motion, effort, efficiency, friction, driver, follower, idler (of pulleys and gears) used in their scientific/technical sense. These answers were marked on a three point scale 0 = no understanding of the concept; 1 = some understanding; 2 = good understanding. All the papers were second marked by an independent primary science specialist and the few anomalies were agreed in conference with a third physics specialist. Even given these precautions it is recognised that these marks can only give a subjective and generalised impression of differences between teachers.

Videos

Each teacher was provided with one of three commercially produced inservice packs focusing on gears, levers or pulleys. The teachers were asked to work through their packs on their own and prepare a 30 minute session for four children aged 10.

Each video was examined and the way the pack used in the classroom was recorded and timed. The closeness with which the teacher followed the pack was noted under four possible criteria:

- no deviation from the instructions
- minimal deviation where although the activities and suggestions were followed closely, the teacher varied the order slightly and/or made adjustments to cater for individual children's responses
- within the teacher's own framework of other activities
- unconstrained adaptation where the pack materials were used but in a way not suggested by the teachers' manual.

It was also noted when teachers used the pack alongside other resources such as flash cards, work sheets, photographs or actual examples of different mechanisms. Accurate use of the science concepts by the teacher, the children's overall attitude, and the extent to which individual children's needs were matched were also recorded. Two researchers viewed all the videos independently and subsequently discussed and re-examined any inconsistencies.

The packs

Each pack contained construction material, a short manual for teachers and activities for children. For example, the manual in the pack on levers gives a number of examples of levers and background information about them. The pack contains one sheet of three 'concept' models, a card showing how to make a weighing machine and one giving instructions for a type of grab. There are also three extension activities suggested. Most of the activities have teaching hints but there is no overall discussion of how the whole pack might be used. The other two packs have the same format but without examples being discussed at the beginning of the manual.

RESULTS

Relationships among qualifications, knowledge of mechanics and confidence

Initial teacher trainees without any physics qualifications lacked confidence in teaching science in general and regarded the prospect of teaching science with concern. Those with A levels or above, particularly when augmented by occupational experience were more positive and confident. However, according to the assessment of their knowledge of mechanics, two of the more qualified students had a weak grasp of the concepts, indicating that perhaps their confidence was unjustified.

The close relationship between physics qualifications and confidence to teach science was not so noticeable with the experienced teachers, who had generally lower qualifications than the initial teacher trainees. However, those teachers with GCSE or who had attended a substantial primary science course tended to be more confident in teaching science in general. Unlike the students all the experienced teachers looked forward to teaching science to ten year olds with at least some positive thoughts. This attitude was to a large extent justified as all the teachers, unlike the students, had an adequate grasp of the topic area. Indeed the teacher with minimal science qualifications showed greatest knowledge, although he had some qualms about teaching science, indicating that qualifications in science may not be a good indicator of knowledge and understanding for experienced teachers.

Teaching sessions

It can be seen from Table 1 that all but one of the students and experienced teachers made at least minor alterations to the pack to take into account children's questions and their different rates of work. However about half followed the advice of the pack very closely. Close adherence to the pack appears to be more related to the teachers' actual knowledge in the subject area rather than their original qualifications.

TABLE 1
USE OF THE THREE PACKS BY INITIAL TEACHER TRAINEES*
AND EXPERIENCED TEACHERS

Way pack was used	Type of Pack Pulleys	 Gears	 Levers
No deviation		1	
Minimal deviation	4	3	1
Within teacher's own framework	4	1	6
Unconstrained adaptation	1		

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* One student was unable to teach

Influence of the teachers' manual

The time spent with the pack as focus varied quite considerably between the three packs. Nine of the thirteen teachers using the gears and pulleys packs spent the whole 30 minutes using the pack material. The other four spent over 24 minutes with the pack as focus.

However, time spent on the lever pack as a focus varied from only 8 to 27 minutes, the average being 20 minutes. Again, unlike the other two packs, far more additional resources were used. All the teachers showed the children actual examples of simple machines, such as staplers, nutcrackers, garlic crushers, wheelbarrows and bottle openers that work by the use of levers. Some teachers also showed the children pictures and books about levers. This had the effect that more teachers in this group changed the pack to fit their own framework (table 1).

The difference in approach could well be linked to the fact that only the teachers manual for the levers pack included a section on real life examples. This appeared to be sufficient to give the teachers the hint to put the children's work into context. This was a very important inclusion as, judging from the reactions of the children, unless their work was put into some sort of context they found it difficult to understand the purpose of what they were doing.

The strong influence of the manual showed in other ways. All the packs provided many suggestions for questions to prompt children's investigations which were followed by all the teachers to some extent (Table 2).

TABLE 2
TIME SPENT ON INVESTIGATIONS

	Average time on investigation	Variation for each pack
Pulleys	11 mins	1 - 17 mins
Gears	10 mins	3 - 26 mins
Levers	6 mins	2 - 11 mins

The investigations in the manual were either suggested as part of a set of 'concept' models or as part of making a working model of a windmill, roundabout, weighing machine etc. The 'concept' models were in the first part of the manual and only 4 of the whole group of 21 teachers did not use it initially. All the concepts to be covered were on one photocopiable sheet, which the teachers attempted to cover in one session. Consequently virtually all teachers tried to cover all three types of lever in the one session, even when this was not appropriate to the rate of understanding of the children. In addition these 'concept' sheets were usually presented to the children as one continuous task rather than being interspersed with real examples or linked to building working models which would have made them more meaningful. This indicated that even small design differences in published resource materials influence teachers who appear to assume that they have been presented with the 'expert' method.

It is suggested that courses for initial teacher trainees and for experienced teachers should include the critical evaluation of resources. This is also an issue that manufacturers of teacher resources should take note of and ensure that their materials are thoroughly trialled with practicing teachers.

Imaginative adaptation of the packs

Both the experienced teachers who used the pack in imaginative ways have qualifications in science and are coordinators for these subjects in their schools. One tried an oral guided discovery session for two of the four children on what different sized gears might do. The children were then asked to design and make a working device of their choosing. While this pair was working, the second pair built a roundabout following a card from the pack and investigated it.

Although the other teacher used the levers 'concept' sheet for the main part of the session, he introduced the levers activity in a novel way by setting the children two problems. One problem involved finding a way to lift a large toy car with a long stick and the other was to use two sticks to pick up a number of small items, including a ball and wooden block. This imaginative approach was marred by the fact that the teacher appeared to expect the children to have greater knowledge or to be more able to recognise which observations were significant than they actually could. His qualifications in the subject area were some of the highest in the sample which undoubtedly gave him the confidence and knowledge to recognise different ways of using the resource, but on the other hand this very knowledge may have inhibited his ability to appreciate the children's difficulties.

Accuracy of science used and concept match to children's needs

There was no advice in the manual regarding the need to ascertain the children's previous prior science knowledge and experience with constructional material. Consequently only two experienced teachers did this, to the detriment of those children, mainly girls, who could not concentrate on the science concepts as they were unfamiliar with following 2D plans or with using the constructional material.

Most of the teachers used and explained the science concepts involved accurately. Inaccuracies were only noted in three cases, two of which were from students with science qualifications who also had low scores on the pre assessment exercise. They were perhaps over complacent with their knowledge so did not examine the pack carefully. Five teachers gave very good explanations of the science concepts during the teaching sessions. Two of these were teachers with no science backgrounds and with fairly low scores on the pre assessment activity, who had obviously used the teachers' manual to good effect.

There were six sessions where the children were obviously struggling to understand the science ideas that were being presented to them, all of which were presented by student and experienced teachers with qualifications in science. For example one student teacher started by talking about how friction influenced the rotation of the globe and continued by using extremely difficult language. He also covered far too many concepts. This problem was not confined to the initial teacher trainees as two experienced teachers both with qualifications and considerable experience with science used language that the primary children struggled with.

It appeared that those individuals with least confidence in teaching science made considerable efforts to get to grips with the material. They had the queries and problems they had had to overcome fresh in their minds, making their presentations well linked to real contexts and their explanations accessible. However their lack of knowledge occasionally appeared to make them reluctant to handle the children's questions or problems.

CONCLUSIONS

Although having science qualifications influenced teacher self confidence, these were not accurate predictors of the actual knowledge held by the teachers in this sample. In addition teachers who both lacked science qualifications and confidence in teaching science made great efforts to understand the concepts covered by packs and were on the whole successful. Their presentations were usually well matched to the children's needs, unlike some of their more qualified colleagues. However their lack of knowledge occasionally led to incorrect information being given or a reluctance to develop the children's interest. As it is recognised that this is a small sample, these findings will be compared with another group of teachers with respect to several other concept areas during the next academic year.

Physical resources of the type investigated in this project were shown to be of real value to teachers both in providing information to the teacher and giving a model for activities in the classroom, but they can be followed too closely. Therefore, those providing initial and inservice training should assist course members to evaluate such materials and encourage them to experiment with the format. The use of videos can be of assistance. With the agreement of the participants, the videos taken during this project have been used by the student teachers to examine their own practice. Experienced teachers have also used the videos to identify problems of inexperienced colleagues in order to discuss how they might be helped to improve, and a group of teacher trainers has used the material as a way of moderating their own classroom assessments. Although the latter two examples have focused on assisting others, the process of evaluation and discussion has also had the effect of informing the participants own practice in this subject area.

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EXPLAINERS' PERCEPTIONS OF VISITORS' LEARNING AT AN INTERACTIVE SCIENCE AND TECHNOLOGY CENTRE

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ABSTRACT

This paper reports part of a larger study into the learning of the general public during visits to an interactive science centre. Much previous research on visitors' learning has focused on students, whereas the explainers, who have most interaction with visitors, have rarely been used as a data source. Reported here are the views of a representative sample of explainers from a science centre. Data were collected through interviews and conclusions scrutinised by a wider group of explainers. The findings suggest that explainers believe that first, visitors have fun at the centre; second, learning is not the main purpose of the visit; third, their own role is to facilitate understanding of the exhibits, not to teach; fourth, learning occurs when visitors relate experiences at the centre to experiences in the outside world; fifth, analogies facilitate understanding; and sixth, incidental learning, unrelated to the intention of an exhibit, often occurs.

INTRODUCTION

During the last decade there has been a rapid increase in the number of Interactive Science and Technology Centres (ISTCs) both in Australia and overseas. Their development has been driven by a philosophy that these centres offer a means for increasing the awareness of science and technology in the community. By awareness is meant an increase in understanding and a more positive attitude towards science and technology.

A significant capital investment by both the public and private sectors has been made in supporting the establishment and continuation of ISTCs. There should be a question relating to accountability for that investment measured against the anticipated outcomes. Most published studies relating to cognitive and affective outcomes from ISTCs have focussed on children whose visit was part of an organised educational experience (see for example Boram, 1991; Feher & Diamond, 1990; McNamara, 1990). Some research has been directed at determining any cognitive change experienced by children when interacting with exhibits designed to demonstrate specific science concepts (see for example Diamond, 1986; Feher, 1990; Huber, 1991). Perhaps surprisingly, there is little published research relating to cognitive and affective outcomes that result from visits to ISTCs by the public (McClafferty, 1991; Stevenson, 1991), although there is considerable research on what visitors do at such centres (see for example Dierking & Falk, 1994; McManus, 1989; Tulley & Lucas, 1991). In a recent review of informal learning in science, Crane, Nicholson, Chen and Bitgood (1994) point out that compared to research on involvement and exhibit design, visitors' outcomes are rarely measured .

A study into learning by the public when visiting ISTCs is fraught with difficulties. Visitors are from diverse backgrounds and will therefore construct their own meaning from their experiences at an ISTC. As the visit is unstructured, they are free to spend varying amounts of time with individual exhibits and are able to interact with any exhibit they choose. The period of exposure to any particular learning experience is typically short. Further, their post-visit experiences may affect any learning outcomes. Probably the only constant factor is that they have visited an ISTC! Robust experimental conditions would be difficult to apply in any study conducted in such an environment.

For these reasons, a major study aimed at investigating possible outcomes of visits to ISTCs by the public has adopted a qualitative approach. Initial investigations were conducted using the staff at one ISTC as subjects in order to collect baseline data from which a protocol could be developed for collecting data from the visiting public. Of all the staff at an ISTC, explainers are in the best position to observe the visiting public's immediate experiences with exhibits, and they are also likely to have the most interaction with them. Consequently the explainers are an important group from whom to seek initial data. Additional data were collected from visitor services staff members and a sample of the visiting public.

It is notable that explainers have rarely been used as a source of information and to date, only two pieces of published research using explainers as subjects have been sighted. One was a longitudinal study conducted at the Exploratorium in San Francisco aimed at identifying any long term impact their experiences as explainers may have had (Diamond, St. John, Cleary & Librero, 1987). The other was a quality control evaluation study by Butler and Loomis (1992), where explainers were required to evaluate their roles and performances when dealing with visitors. The information was used to develop new management procedures. No study examined the views of explainers about the learning of visitors. This paper reports explainers' perceptions about the learning of the visitors to an ISTC. The data analysed form part of the baseline data from an ongoing study.

METHOD

Subjects

"Docent, volunteer, interpreter, and instructor are some of the names given to those who 'translate,' 'decode,' or explain and describe exhibits" (Grinder & McCoy, 1989, p. 3). Explainer is another name and is used at the Exploratorium (San Francisco) and Questacon (Canberra). The roles for explainers generally include informal welcome of visitors, assistance at and interpretation of exhibits to visitors when appropriate, encouraging visitors to extend their interaction with displays by supplying background information, suggestions and anecdotes and assistance with demonstrations.

All the explainers at the ISTC in the study are volunteers, but their selection is made very formally. Recruitment is by word of mouth and notices on university noticeboards. Applicants for explainer positions must be a minimum of 18 years of age. Each applicant participates in a formal interview conducted by the Explainer Coordinator, during which the applicant is assessed for suitability according to the following criteria: friendly, outgoing personality; willingness and ability to extend their own knowledge of the centre's displays; commitment to act as an explainer for five hours per month; and prepared to undergo a training program and 20-hour probationary period.

The training program involves two six-hour sessions in which permanent staff familiarise explainers with administration, public relations, visitor service, exhibit design and construction, theatre demonstrations, school tours, and exhibit floor layout. Trainees also spend time observing experienced explainers interacting with the public. They are then required to practice being an explainer with their peers playing the role of visitors. Next they are assigned to an experienced explainer who acts as a mentor for their probationary period. After they have completed the training program and probationary period they are able to act as an explainer without supervision.

For the purpose of this study, the Explainer Coordinator selected a sample of ten explainers from a pool of approximately one hundred to form a focus group for discussion. She had been informed of the objectives of the discussion prior to that selection being made. Experience as an explainer and potential to articulate ideas in a group setting were considerations when prospective participants were approached to be part of the focus group. The group of eleven consisted of six females and four males as well as the female Explainer Coordinator. Their ages and backgrounds were varied. Some were retired and others were university students. Most had a background in science, but some did not. The experience of the explainers ranged from one to five years.

Procedure

The most convenient and efficient method of collecting data from the explainers was to hold a group discussion. This approach allowed for the development of a pool of data that would give an insight into the explainers' perceptions of visitors' experiences. The session is described as a focus group because it was "a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, non threatening environment" (Krueger, 1988, p. 18). The number of participants fell within the range of eight to twelve considered to be optimum for a focus group. When an investigation is designed to find how people regard an experience or event, focus groups are considered to be an appropriate environment (Krueger, 1988).

The group met on a Sunday afternoon for a period of one hour under the chairmanship of the first author. Prepared questions were put to the group and discussion among them was encouraged. Most questions were open ended and dichotomous questions were avoided where possible (Patton, 1990). At the beginning of the session it was emphasised "there are no right or wrong answers, but rather differing points of view" (Krueger, 1988, p. 25). The intention was to provide an environment where participants were able to react to each others' comments and stimulate responses and ideas that may not be forthcoming in a formal interview setting.

The first question invited explainers to use one minute each to relate their experiences with science when they were at school. That question gave each participant an opportunity to speak and was designed to be an 'ice-breaker'. At times probing questions, different from those which had been prepared, were used. The facilitator was careful not pass judgement on any statement. "It is the role of properly conducted focus groups to 'unpack' the cabin trunk of experience and piece together the answers to these questions" (Hall, 1991, p. 238).

The session was recorded on an audiotape with prior consent of all the participants who were given an assurance of anonymity. When the audiotape was transcribed all responses were coded to maintain anonymity and to provide for a guide to each individual's input through the session. A check on the accuracy of the initial transcription was carried out by replaying the tape and some corrections were made.

Data Analysis

The transcripts were analysed by carefully reading and comparing all responses which related to explainers' perceptions about the visitor experience. Natural categories, grounded in those responses, were developed. Data were summarised by preparing generalisations, described as general perceptions, based on those categories. The validity of these generalisations and their source statements were tested using another group of ten explainers approximately six months after the focus group session. This second group were volunteers from a larger group of explainers who had met at the ISTC to receive instructions about a new exhibition from the Explainer Coordinator. The first author again acted as chairperson for the discussion with this second group, which will be referred to as the review group. On this occasion there were ten participants, three of whom were participants in the original focus group. This allowed a process called member checks (Lincoln & Guba 1985) to assist validating data. The participants worked in pairs. Six sheets, each with a generalisation together with its confirming and any disconfirming statements gleaned from the data collected from the original focus group, were given to each pair to read and discuss. The group as a whole were then involved in a discussion to comment on the appropriateness of each of the generalisations and associated statements.

RESULTS

The results are reported in terms of the general perceptions identified from analysing the data, and illustrated by some of the comments made by the explainers in the focus group. In addition, confirming and disconfirming statements given by the review group are reported.

Perception 1: Members of the visiting public have fun at the centre. When the question, "do you think people enjoy their visit to this ISTC?", was put to the focus group there was an animated reaction. A cacophony of affirmative comments indicated the extent of certainty by the explainers that visitors did indeed have fun when they visited the ISTC. Some example comments from the focus group were:

> [The] only thing they don't enjoy is when you [parent] take them [children] home.
> One old lady was having a ball. [She said] "my grandchildren talked me into coming and I think it's wonderful."
> Even the school groups [have fun]

The unanimity within the focus group is not surprising as all of the advertising aimed at getting the public to visit the centre has both obvious and subtle messages emphasising enjoyment (M. Henry, personal communication, April 22, 1994). This perception was supported by the review group. One review group participant commented that "a large proportion of visitors return voluntarily and pay money to do so makes it obvious they enjoy their visit(s)." Research conducted by the ISTC marketing section lends support to that respondents' view as it revealed 83 percent of visitors have been before (M. Henry, personal communication, February 8, 1994).

Perception 2: Learning is not the main purpose of the visit. "While they (visitors) are having fun are they learning anything?" was the second question put to the focus group. One explainer was quite emphatic in her view of the philosophy behind ISTCs. Quite in contrast to the view of the Explainer Coordinator, this person firmly believed that learning was not part of the reason for the existence of ISTCs. She stated that the "philosophy behind this place is not a teaching institution but entertainment." When she made that point there was no direct support of her view from the other explainers. However, during later discussions arising from other questions to the focus group, there were some statements made that added support for her belief:

> People enjoying themselves and learning something are two very distinct things and if they are out to enjoy themselves they are not out to learn science whether they are learning or not.
> Somewhere to go to have fun. Ten to thirteen [year old] bracket don't listen. They have a glazed look and just want to go and play by themselves.
> A lot of people think "I'm here to have fun and not to learn" and they turn off [when taught] if you like. Especially the young teenagers.

One member of the review group commented that the previous statement would be appropriate only if it referred to some people rather than a lot.

Another statement indicated qualified support for the notion that ISTCs exist for enjoyment only. However, that explainer clearly believed a visit to an ISTC was not exclusively for enjoyment and that some learning was associated with the experience.

> I go to [the] Art Gallery and [the] Museum. A lot of expressions on faces are entirely different. [The] Art Gallery and Museum are definitely learning and ISTC fun and learning.

The review group indicated their support of this perception.

Perception 3: The role of an explainer is to facilitate understanding of the exhibits, not to teach. When explainers at this ISTC undergo their training program, part of that time is spent learning how to "encourage visitors to extend their interaction with displays through anecdotes, background information and suggestions" (J. Pyke, personal communication, July 24, 1993). One focus group respondent succinctly stated they were "not taught to teach." Explainers in the focus group saw their role as that of assisting visitors with explanations of exhibits when they believed it to be appropriate, e. g. "Part of the job is being able to discern who wants to know what and who doesn't."

They perceived their primary role as assisting people to think about and understand the scientific concept or concepts an exhibit had been designed to demonstrate. Didactic explanations were seen by explainers to be of secondary importance and not the preferred method of interacting with visitors.

> Some people come in here and think people [explainers] who go to university are very clever people and expect them to remember [the] basis of DNA. We are about understanding principles rather than rote learning.

However, some explainers in the focus group felt that although they tried to encourage people to seek their own answers, there were occasions when direct imparting of knowledge was appropriate.

> Although we are not [here] to teach people we may roll [end] up doing that. For example, [the exhibit about] the tongue and its relationship to smell and [the visitor is] often very interested and appreciate having it explained to them. Some want to know ... others don't.

The members of the review group were unanimous in their support of this perception and there was little discussion by them about it.

Perception 4: Learning occurs when visitors relate experiences at the centre to experiences in the outside world. Explainers in the focus group were able to describe a number of instances when visitors had been able to understand the scientific principle being demonstrated by an exhibit when they linked it to a previous experience away from the ISTC. In some cases the visitors were from a science background and, in their job, they had been using specialist equipment or had experienced related scientific phenomena. By using their experiences at the ISTC and the outside world they were able to understand better the scientific principles involved in their work.

> Gyros! [One visitor was] an engineer and when we [ISTC] used to have a suitcase with a gyro, [she/he] said, "Oh yes, we used to use gyros in engineering". They apply it to their own experiences. Another worked in aeroplanes. He related static electricity to his experience at getting a shock from aeroplanes. So when they saw the science behind the experiences, it was interesting. It's mainly from people with engineering experience that can apply [the principle] if they've never seen the science before.

Some of the focus group explainers indicated they had seen scientific principles at the ISTC that helped them personally understand an outside experience.

> ... for me the Special Effects [an exhibition that focussed on creating illusions on film] has helped understand movie effects. Aha! I know how that is done now.
> Yeh! I do that too. (Two other respondents)

One focus group respondent indicated that he had been involved in a technical occupation before retiring and becoming an explainer at the ISTC. Since being at the ISTC he had been able to link some scientific concepts to his previous occupation. He said he was

> ... now able to understand the science behind a lot of things I did. When I was working I did things without thinking about it.

Other focus group explainers were able to relate comments made by visitors that clearly indicated a link was being made to the world outside the ISTC.

> A boy playing with archway ... said he had archway in his house. It's wedged together like this.
> [An] eight year old looking at damage to the lung said "My dad smokes. Does that mean he is going to die?"
> ... one of the girls had once smoked a cigarette and she was worried that her lung was going to be like this all the way through.
> Heart coronary by-pass [exhibit]... [the visitors] relate to [their] families.
> Lung also. "So and so has that disease" and they are all pointing to it.

In reference to two exhibits designed to demonstrate differential rates of thermal conductivity, a focus group participant reported that " [It] amazes people that [the] steel one [toilet seat] feels colder than one of the other ones. Three cars also [different colours]. Often see people talking about that." The review group supported this perception. There was considerable confirming discussion by the review group about the experiences visitors bring to the ISTC and how it affects their reaction to exhibits.

Perception 5: Analogies facilitate understanding. When visitors were having difficulty being able to understand the scientific concepts that an exhibit was designed to portray, explainers found that the use of an analogy could be useful. One member of the focus group reported that:

> Analogies work .... people go 'ah I get it'. I use simple analogies to explain and be able to link principles.
>
> For example spinning chair is like a skater on ice [angular momentum]

Another focus group explainer gave an example of using an analogy that linked the exhibit to the visitor's occupation. In doing so an analogy was used to link to a very direct outside world experience. He was explaining cancer to a motor mechanic:

> ... cells [behave in an] unregulated fashion like having your foot stuck on the accelerator. He clicked onto that straight away. [I was] tailoring that analogy to something he was familiar with.

Rather than using an analogy that is directly related to the principle it is being used to explain, it is possible to use an indirect analogy in order to facilitate understanding. A focus group member gave the following example:

> Sometimes you need to link the opposite analogy for people to click. For example [the exhibit that shows] air pumped out and water boils. [The] classic example [is] you can't boil an egg [at 100°C] on top of Mt Everest. But for most of us, that isn't particularly relevant ... If you turn it the other way round ... higher pressure water boils at a higher temperature can be illustrated by a pressure cooker. Most people have seen food cooking faster.

The review group also indicated that analogies were an important tool for them to use when helping some visitors understand particular exhibits.

Perception 6: Incidental learning, unrelated to the intention of an exhibit, often occurs. Exhibits are developed according to specific educational objectives. These objectives are taken into account early in the planning stage of an exhibit. They are arrived at in meetings between staff of this ISTC in the areas of education, graphics, marketing and technical services who construct the exhibit on site. The objectives indicate anticipated learning experiences as a result of a visitor interacting with an exhibit designed to demonstrate scientific principles (V. Dodds, personal communication, May 3,1993). The focus group of explainers were able to give a number of examples where learning had occurred that was different to the educational objectives of an exhibit.

> People learn without realising it. I've got two children between six and eight who come in very frequently with me. They don't understand the science behind it, but they know what happens if they press a button due to the frequency of their visits they have learnt what to expect. They really do pick up a lot of knowledge.
>
> Whispering dish. [Visitor] played around with the telescope piece to see how it works .... looking at the ball and socket joints rather than see how the telescope works.
>
> Lot of fun spinning it [telescope piece of whispering dish] around and see how joints work. Observe parent explaining to a child.
>
> Chicken exhibit designed to show hatching. Most people are looking at behaviour rather than purpose [of exhibit]. Tapping on edge may sound like the mother.
>
> Mice behaviour ... food. Most just look at them running and how they eat the food [exhibit designed to demonstrate genes].
>
> Very small children going up and down [the] parabolic dish. Parents realise their child can actually climb up and down without hurting themselves. Parents learn themselves. Even very small babies' eyes light up perhaps reacting to noise ... originally I thought there was nothing for little children, then I realised there was a lot.

All members of the review group concurred that unintended learning does occur at the ISTC.

DISCUSSION

The data showed there was considerable agreement between the explainers involved in this study enabling their ideas to be summarised into six general perceptions about the visitors' learning. The agreement becomes more significant when the variety of backgrounds and ages of the explainers are considered. Further, the general perceptions were confirmed by a second group after six months, giving strong claims for validity in interpretation of the findings from the focus group.

The explainers' contention that visitors enjoy themselves has been supported by data collected by interview and questionnaire in the second phase of the major study. All of the 35 visitors thus far interviewed indicated they felt their visit had been fun. Only one out of 48 people who completed open ended post-visit questionnaires did not indicate any enjoyment during their visit. The notions that people experience incidental learning, relate concepts demonstrated by exhibits to their own experiences, and find the use of analogies assist their understanding have all been confirmed by data collected from interviews in the major study. Those data also indicate that people choose to visit the ISTC for reasons which are related to entertainment rather than learning.

Whether or not people come to an ISTC to learn is an interesting issue. ISTCs have learning objectives in their manifesto, educational exhibits are designed carefully to provide experiences which are enjoyable, but are also intended to promote understanding of the concepts involved and to stimulate interest in science and technology. That at least one explainer did not perceive this to be part of the "philosophy behind this place" suggests that the entertainment dimension of the ISTC visit is an important issue. There is little doubt that some learning does occur as the exhibit designer intended, however such learning may well be incidental if the visitor's intention was enjoyment.

The explainers provided a rich source of qualitative data. The focus group provided a unique insight into the explainers' perception of visitors' experiences at an ISTC, which have not been documented before. All members had first hand experiences to relate providing consistent information about what visitors are perceived to do and learn. The ISTC involved in this research was typical of such centres, and the explainers were chosen carefully to be representative. However, further research is required to determine whether the findings are generalisable to other ISTCs.

Explainers, as sources of information, offer opportunities for further research. Investigations in ISTCs relating to education, exhibit design, visitor service, and marketing should all be able to obtain data utilising explainers. This also applies to museums, zoos, and art galleries that use explainers to interact with visitors. If ISTCs and other centres for informal science learning are to demonstrate outcomes related to increased awareness and understanding of science and technology among visitors, then every research avenue must be explored. As noted by Bitgood, Serrell and Thompson (1994), we should be developing new methods for research in informal settings such as ISTCs.

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TECHNOLOGICAL PROBLEM SOLVING IN TWO SCIENCE CLASSROOMS

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ABSTRACT

This paper reports on the analysis of student (aged 13-15) technological capability as they undertook technological tasks in science classrooms. The activities covered a number of different contexts, had differing degrees of openness, and methods of presentation. An holistic approach to analysing student performance was developed and this provided insights into the approaches adopted by the students. The focus of students on an end-product meant that students did not fully consider the process that might be required to solve the problem. The strategies, skills and knowledge they brought to bear were often not appropriate. Present classroom cultures and contexts need to be understood as greatly affecting performance in technological problem solving.

INTRODUCTION

This paper reports on the analysis of student performance in the technological activities, and focuses on the technological capability of science students aged 13-15 years. This research was carried out 12 months before the distribution of the draft *Technology in the New Zealand Curriculum* (Ministry of Education, 1993). Teachers involved in the project were encouraged to introduce technological problem solving in advance of the curriculum statement.

As noted by Jones and Carr (1993a), context plays an important role in the student performance in a technological task, hence throughout this report reference will be made to the contextual settings. These contextual settings encompass the tasks that students are engaged in, the classroom in which they are taking place, and the students' expectations of the learning situation.

Technological capability was explored through students carrying out problem solving activities in a variety of contexts. The development of a technological solution is a complex activity which involves: identifying problems; gaining, adapting and applying technological knowledge and skills; gathering information from a variety of sources using a variety of techniques; identifying needs and opportunities; exploring ideas; modelling, developing and testing; communicating, reflecting and evaluating; and taking into account societal influences.

Evidence for some aspects of capability are highly ephemeral (Kimbell, Stables, Wheeler, Wosniak & Kelly, 1991). Technological capability has been traditionally based on the permanent outcomes from a technological activity (Kimbell et al., 1991). Artefacts, written outcomes or folders of information which have been tidied up after the event may not reveal this process, hence in this research several different approaches were developed to explore and report upon students' technological capability.

METHOD

The four methods of data collection were classroom observation, individual and group interviews, teacher interviews and analysis of outcomes (written and non-written). These methods were used to develop a 'picture' of student technological capability which was manifested in different forms and in different ways. Classroom observations allowed for the general context of the setting to be explored and allow consideration of at least some of the variety of influences that may be affecting student performance in the task. Individual and group interviews provided a rich exploration of the student interaction with the task throughout the process. Group interviews were valuable since the students often worked in groups and the research was not restricted to an exploration of individual technological capability. The teacher observation and comment allowed for further consideration of the context and the teacher's views on student performance. Written outcomes completed during and at the end of an investigation provided further information on the processes and the outcomes. This rich assessment procedure enabled the researchers to monitor the actions of many students over a 10-16 hour investigation.

The procedures adopted provided for an holistic analysis which was required since technological activity is so integrative. An assessment of technological capability which concentrates on atomistic units of assessment may be more reliable but is not necessarily a valid assessment of technological capability.

Process of analysing technological capability

The analysis was undertaken in three areas: students' responses to the requirements of the technological activity; total process of students carrying-out the technological activity; and the influences on that process.

The students' responses to the requirements of the technological activity were analysed using significant features from the responses as categories. The categories used were; reasons for choice of task, planning questions, knowledge and skills they think they have and anticipate they will need, and perceived learning outcomes.

In representing a large amount of data, from a variety of sources to explore student technological capability this research has found it valuable to analyse the process of technological problem solving by developing the concept of a pathway. These pathways represent the procedure which describes all the students' responses, though individual students use different features of this pathway. These pathways do not represent an ideal process of technological problem solving but are rather an abstraction constructed by the researcher from interpretation of the classroom data. Fig. 1 describes the pathway abstracted from the science classroom data.

The figure identifies key stages in the students' process of solving the technological problem and establishes an overall pathway through these stages. Numbers can be used to describe a particular student's process and can be represented in any order. For example student A may use a process described as [1>2>3>6>7a]. This process involved reformulating an initial idea and considering a number of factors then progressing to developing a possible solution and making a cardboard model. This student did not consider the need to plan and carry out any research, did not develop an appropriately detailed design, and did not carry out any evaluation. Another student B may use a process described as [1>2>3>4>5/1>6>7]. This process involved reformulating an initial idea and considering a number of factors then progressing to a planned research, which required gathering some information. The figure includes a feature described as displacement. This is used to identify activities that have digressed from the technological task. For a full description and analysis, see Jones and Carr (1993b).

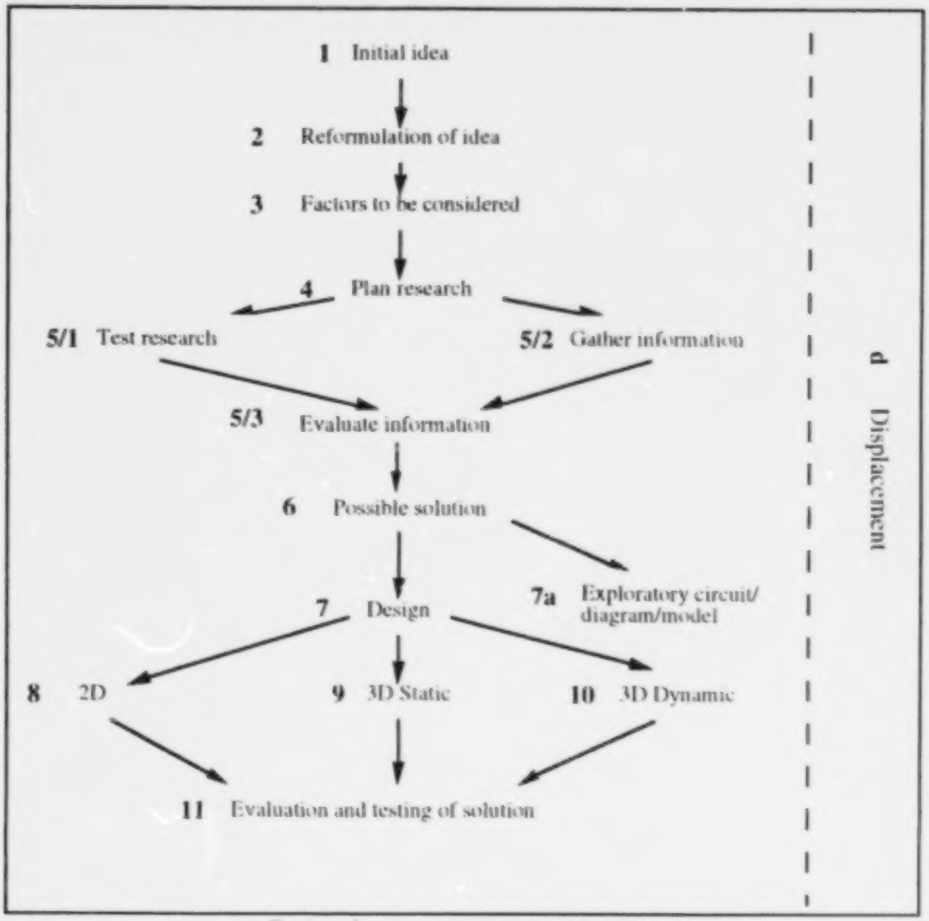
1 Initial idea
2 Reformulation of idea
3 Factors to be considered
4 Plan research
5/1 Test research
5/2 Gather information
5/3 Evaluate information
6 Possible solution
7 Design
7a Exploratory circuit/ diagram/model
8 2D
9 3D Static
10 3D Dynamic
11 Evaluation and testing of solution
d Displacement

Fig. 1. Technological problem solving pathway

TECHNOLOGICAL CAPABILITY OF SCIENCE STUDENTS

Background to year 8 science class

This was a mixed ability year 8 science class of 28 students. Data were obtained from 11 girls and 15 boys. The students had previously completed a section of work on electricity and were required to design an electrical product or system to meet a particular need. There were eight one hour lessons spent on this activity. The students selected the following activities: door bell for deaf people; bedroom bell; phone/light for deaf people; overflow alarm; electronic locker key; an electrically controlled valve for drinking fountain.

Students generally did not consider using outside resources, and limited themselves to equipment available in the science laboratory (mainly batteries, bulbs, wire and switches). One group of students explored other types of switches, solenoid valves and drinking fountain mechanisms.

All the students were able to focus on the problem area and also began to develop ideas about appropriate solutions. The group designing the timer for the drinking fountain identified the problem area and the parts of the system that they would have to consider. The group designing an alternative locker key clearly identified the problem area but focused on a 'hi-tech' solution (eg integrated circuit) using 'low-tech' material (eg cardboard and wires). Both groups developing a doorbell for the deaf considered a range of ideas and were able to identify the problem area but the solutions utilised simple science classroom material. Hence, the students' focus was in terms of a simple model rather than more realistic factors. The group developing a bedroom security system thought about the factors in terms of materials to use but did not consider possible solutions whereas the group developing an overflow alarm considered possible material in relation to possible solutions.

Year 8 technological process

The analysis of the students' process will be discussed in terms of each group of activities; security, timer for drinking fountain, doorbell for the deaf, alternative locker key, and overflow alarm.

The students working on the security task wanted to complete something to show to the class and this often influenced what they did in their investigation. They did not identify what they knew or could do in relation to the problem they had set themselves. They identified that they wanted to use an electrical bell in the design and spent most of the time getting a bell to work. They wanted to include automatic locks and alarms with appropriate switches. However, this was not investigated and in order to present something to the class they connected up a bell and battery. In terms of a final solution they changed their initial idea to relate to the solution they had developed and made a doorbell.

The group, developing a timer for a drinking fountain, asked initial questions related to how things worked and they focused on the parts of the system rather than the whole end-product. For example, they considered that they would need some sort of timer, a valve and an understanding of how the drinking fountain worked. They spent considerable time investigating these. This process took them through steps 3>4>5/1>5/3. At step six they developed a possible solution by linking the three parts of the system together and began to develop a design. Although they did not progress further they had developed a realistic design. They developed an understanding of how things worked. They did not consider any ideas related to implementation.

A group investigated a doorbell for the deaf. The students identified some of the physical principles involved. However, in carrying out their activity they only investigated one aspect even though they had identified others. Already at this stage they were considering presenting a model in terms of cardboard, batteries and bulbs. The students did contact an outside source to gather information (5/1) but did not use this in developing their model. The students moved to step 7a because they needed to present it to the class. They realised that they could have done more in their activity to improve their solution but were focused on a model. The students were concerned about the cost of commercial bells and saw this as a reason for their investigation. However, once they focused on developing a cardboard model, costing, benefits, etc for the consumer were ignored. The focus on the model meant that they did not even consider how a door bell might work or other options.

A second group investigating a doorbell for the deaf focused, from the outset, on making a cardboard model of a house and this influenced the process that they went through in developing a solution to their technological activity. Therefore they progressed from an assumption that they would have to present something that worked. This meant they asked simple questions rather than considering factors related to the real use of the device. They carried out no research and went to trial-and-error circuits (step 5/1). From this they moved directly to Step 7a and spent time making a model of a house. The focus on the model meant that they could replace a door bell and a telephone with a simple switch. The real use was not considered, ie how a deaf person would know if someone was at the backdoor. This was not considered to be a problem for the students.

A third group investigating a doorbell for the deaf also focused on a cardboard model. In considering a variety of factors they did not ask questions nor did they think about what they knew or could use, rather their focus was on presentation. This meant that they did not see the need to do any research. The process that these students went through was very similar to the other group's investigation of a doorbell for deaf people. During the interviews with these students it became apparent that they had good ideas which they could have used in their investigation but did not do so because they were focused on making a model that could be presented to the class. They did not want to take risks. One student in this group stated that: "we did something we knew we could do then we would get better marks".

The group which investigated alternative locker keys thought of ideas such as key pads and card access systems. Initially they thought they would be able to make such a control system. They did focus on appropriate factors and considerations but their questions were general and concerned with end-use rather than the specifics of operation. Their knowledge about simple circuits influenced the way in which they thought about how these devices might be designed, eg batteries, bulbs and wires. In planning research (step 4) the students were able to identify suitable questions but they did not investigate these and only thought about using the library as a resource area. The students moved directly to 7a.

The group investigating the overflow alarm focused on developing exploratory models as a means of developing their design. The model was not considered by these students to be the end-product but rather a means of developing ideas. In taking into account a variety of factors the students used knowledge they had gained in other areas of science, such as conduction and different types of solution. In step 4, students decided to test out a number of ideas to find which would be the most appropriate. From this step they moved to test out their ideas (step 5) involving a number of different set-ups. From testing-out their ideas they were able to develop a 'black box' approach to developing a system (step 6). This was tested-out by developing a simple exploratory model using a power supply conductors, ionic solution and a bell (step 7a). As a consequence of this step the students began to develop a possible design for their alarm. However they saw this stage as being the completion rather than thinking about a final system.

Year 8 students' general strategies and outcomes

The students (20%) who were focused on making an end-product developed a strategy to explore the problem area and using their knowledge of electrical circuits. The other students (80%) in the class were focused on making a model to present to the class, rather than using a model as a means of exploring ideas towards developing an end-product or system. Three of these students after the presentation began to develop a more appropriate and complex system. The focus on a model as the final outcome meant that for four students there was no perceived need to research or explore ideas.

Seven students felt they had developed more knowledge about electrical devices during their technological activity while four students stated that they had learnt about scientific concepts. Six students indicated that they had learnt more about electrical circuits than they had in other science classes. Although students did not comment on the process they had been through in solving these technological activities, six students did state that they found it difficult to develop appropriate solutions. The students who took risks in developing possible solutions learnt more than those who 'played safe'. For example, two students stated that they did not learn anything because they had done it before and yet they developed very simple circuits as solutions to represent complex problems.

Background to year 9 science class

This was a mixed ability fourth form science class of 31 students. Data were obtained from 10 girls and 11 boys. This technology unit was undertaken in place of a unit of work on Chemicals in our World. The general area of investigation was pool chemicals. The technology unit of work took 12 hours of class time, and the pupils also used their own time to visit businesses and public pools. The students selected the following to investigate; which is best, dispensing chemicals, reactions of chemicals, safe storage, marketing chemicals, and toxicity of chemicals for public use.

The students were free to use their science class time to collect information from the library, to contact business or to use other rooms such as the computer room. The students were also encouraged to visit public pools to collect information and to make contact with and visit pool chemical distributors and manufacturers. The students spent considerable time contacting these businesses. Business was always helpful in providing what information they could. The students discussed ideas between groups and also informed the rest of the class what they were doing and the progress that they were making. Some suggestions were made by other members of the class and the teacher.

The students were generally clear about who would use the outcomes and where they might be used. When the students came to consider what might be required to solve the problem and how it will be used, the response from the majority of students was very general. Thirty-eight percent of students were more specific about what might be required. The responses suggested a way in which they might undertake the task. For example, pool water samples, analysis equipment and procedures, provide information for issuing chemicals compared with responses such as chemicals, materials.

The student responses indicate that there was a wide range of knowledge and skills they were able to identify that might be required to carry out the task. For example, the group which investigated toxicity was able to identify their knowledge about the effects of chlorine and some of the skills they had in terms of the way they were going to carry out the activity. However other students were often unsure of the knowledge required or the necessary skills. Other students identified aspects of the design of the end-product, rather than knowledge and skills that might help them carry out their activity. The knowledge and skills identified by the student appeared to be a reasonable indicator as to the way in which students carry out the whole task. The greater the knowledge and skills identified by the student the more likely they were able to complete the activity.

Year 9 technological process

The process that the students went through in solving their technological problem will be discussed in terms of those who used a research approach, a design and make approach and a combination of the two.

There were 16 students (76%) who carried out a research-type technological activity. Four students went through the process of 1>3>4>5/1. The activity was well planned but their ideas were not translated into action. The experiment (titrations) was not related to the questions that they set out to answer. Another group of five students went through the general process of 1>2>3>4>5/2. These students did not have focused questions and this caused problems in terms of ways to collect the information they required. For example, one came to a conclusion based on their own previous experiences rather than related to the research undertaken and outcomes.

Four students went through the process of 1>2>3>4>5/2>5/3 ie. they evaluated information collected but did not draw conclusions in relation to their initially posed questions or evaluate the process they had undertaken. These students wanted to find out what was best on the market and had difficulty getting information from traditional sources. They believed the information would just be available, and were unsure of what to do when it was not. This reflected their expectations in that they had traditionally been given any information that they might require in class and that they could solve a problem in a linear fashion.

Two students carried out a solely design and make activity (making a new label) and went through the process of 1>2>3>4>5/2. Their questions did not relate to the proposed design. They developed a label but existing labels were not taken into account and yet this was a requirement in their proposal. The research that they carried out in the form of a survey appeared to be an 'add on' to the activity rather than an integral part.

Three students carried out a combination of a design and make activity and a research activity. These students went through the process of 1>3>4>7>1>3>4 and tried to create a new product and then research what was available. The focus appeared to be on making a dispenser and not testing it out. This meant they did not consider aspects such as cost, efficiency, etc. They researched what was available as an 'after-thought' rather than the research informing their designing and making. The process these students went through did not relate to their initial questions and ideas.

Year 9 students' general strategies and outcomes

The four students investigating toxicity saw this activity as being different from what they were traditionally used to in the science classroom and were unsure how to act. Although they had carried out similar activities in other programs (for able students) they did not use knowledge and skills they had developed in these other programs. Other students thought that the teacher would tell them what to do and that they would not be given a problem that did not have a right answer.

In terms of making a product two groups of students had different ideas, one thought that since they could not make it they would not design it whereas another group thought they had should make something rather develop an appropriate solution. This second group thought that collecting information might have been enough to satisfy the teacher's expectations. One student's personal goal was to collect information on chemical reactions, not to solve technological or even scientific problems.

For the students in this science class the amount of responsibility given for their own learning was new. Many students they felt that the rules had been changed and they were unsure how to respond. In this class there was a mismatch between questions posed by the students and the strategies required to answer those questions. Although many of the students had the knowledge and skills to carry out the technological activities from a range of subject areas they did not use them. The students identified knowledge that they had gained in carrying-out the activity. This knowledge was often in terms of ideas about the existing technology concerned with pools or in terms of chemical reaction and analysis. The students did not comment on the process they had been through. The results for some students indicates the type of learning in science that can result when students are engaged in technological activities.

DISCUSSION

The classroom culture and student expectations appeared to strongly influence the way in which students carried out their technological activities. In the Year 8 science class, the expectation of 80% of the students was to make a model to present to the class. This limited their approach to possible solutions. In the Year 9 science class the students were accustomed to being provided with information. In a less structured environment where problems were to be identified and solved they were unsure of what to do. They transferred little knowledge from outside the science classroom. Many students felt that the rules of the classroom had changed and did not know how to respond.

The expectations of students (often focusing on an end-product) frequently affected the initial planning of solutions. In the Year 8 science class the activity was linked to some previous learning. The students identified the knowledge required and how they might use it to develop a solution, but the solution was a cardboard model. Only one group considered the development of an appropriate solution. In the Year 9 science class 38% of the students suggested strategies related to how they might undertake the task compared with those students who responded in a general way.

Since students were often identifying factors at a superficial level it was difficult for them to consider the knowledge and skills they might require to solve their problems. When students focused on a model only, or considered an inadequate process, they frequently identified knowledge related to the general features of their desired end-product rather than knowledge that might be required to solve the problem. The knowledge and skills that they identified appeared to have considerable influence on how they tackled the tasks. Those students who could identify appropriate knowledge and skills could often complete the technological problem in a realistic way. In the Year 9 science class the students (19%) who were clear about the focus of their activity could identify knowledge related to investigation. The other students were unsure of the knowledge required or they identified knowledge related to the design of the end-product rather then the knowledge and skills that might help them in their activity.

With the focus on models in the Year 8 science class none of the students progressed beyond the exploratory circuit/model stage of the process. The students who focused on a model saw no need to carry out research or collect information related to the problem. The one group who collected information did not evaluate it. The group who did not focus on a model designed the research, collected information and evaluated it. A group that attempted to be innovative also explored a number of ideas and carried-out and evaluated their research. In this class those who 'played safe' by making a model limited their opportunities to show technological capability whereas these students who were being innovative asked questions, collected information, explored a number of ideas, considered systems and began to develop appropriate solutions.

In the Year 9 science class, groups used three approaches (design, research, and design and make) depending on the required outcome. Seventy-six percent of the students used a research approach but often their ideas were not translated into action (for example, the experiments did not relate to their questions, lack of focus in collecting information, and conclusions that were not related to their initial questions). It was found that the planning questions asked by the group undertaking a design and make activity did not relate to the proposed design. In this class there was a mismatch between the questions posed by the students and the strategies required to answer those questions. There was a need for on-going reflection and evaluation.

It was noticed throughout the analysis that there seemed to be a gender difference amongst able students. For example, in the Year 8 and Year 9 science classes some more able girls were more willing to take risks and develop a systems approach to solving their problems. The boys on the other hand played safe and did not want to try out new ideas. The girls were more innovative.

The students in the classrooms involved in this research enjoyed carrying-out technological problem solving and their teachers reported considerable enthusiasm for these activities. This research has probed many aspects of classroom teaching and learning in an attempt to analyse the technological capability of students. The main conclusion is that present classroom cultures need to be understood as greatly affecting performance in technological problem solving. The focus of students on an end-product meant that students did not fully consider the process that they might require. The strategies, skills and knowledge they brought to bear were often not appropriate, appropriate questions were not asked at the crucial stages, and systems were not considered.

When technological problem solving is introduced into science classrooms, students are interested, enjoy the experience and in many cases learn some scientific concepts. There is very little evidence of transfer of scientific knowledge to technological solutions and little understanding of the processes involved. The technological process adopted by the students is somewhat fragmented and appropriate solutions are not forthcoming. The culture of learning in science classrooms does not appear to lend itself to helping students develop technological capability in any holistic manner. The introduction of technological problem solving into science classrooms needs careful consideration if technological capability is a desired learning outcome.

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IMAGES IN MIRRORS: RECOLLECTIONS, ALTERNATIVE EXPLANATIONS AND MODES OF COGNITIVE FUNCTIONING

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ABSTRACT

Students' conceptions of how objects are seen directly, and in mirrors, were explored in an analysis of their written and drawn responses to common visual phenomena depicted in cartoons with brief text. Students in Grades K-10 (n=214) completed a questionnaire and some were interviewed. Evidence was sought to support an hypothesis for increasingly sophisticated responses related to the concepts of sight, light, reflection and image. The developmental model used in this analysis was the updated SOLO Taxonomy (Biggs & Collis, 1991; Collis & Biggs 1991). It appears from the results that different modes of functioning can interfere to produce factually incorrect recollections of experience particularly in the age group 7 to 13 years approximately. Also, this is associated with the common spurious conception that mirrors have a lateral inversion property. Explanations involving light were extremely rare and its role related to the production of an image 'in the mirror' but not to the perception of an image in the eyes.

INTRODUCTION

Research in the area of students' alternative conceptions in science has generated many hundreds of papers in the last two decades (Pfundt & Duit, 1991). The majority of these papers attempt to map the most common conceptions in various school science topics and raise important issues about effective teaching and learning methods. For example, in the topic of light and vision, students' beliefs about the nature and behaviour of light have been described by Stead and Osborne (1980). Also, a range of beliefs about how we see objects have been reported by Andersson and Kärrquist (1983) and Guesne (1985) from studies involving Swedish and French speaking students respectively. More recently, the ideas of Australian students concerning phenomena related to light and the process of seeing were collected in a questionnaire study conducted by ACER (Adams, Doig & Rosier, 1990). In their analyses, researchers have drawn attention to the similarity of some students' conceptions to those recorded in the history of science and also to their persistence in spite of serious teaching of currently acceptable scientific views. However, it appears that few analyses of this type of study have involved a consideration of the nature of cognitive processes involved in the different types of responses given by students to stimulus questions or situations.

A developmental model of cognitive functioning based on the SOLO Taxonomy (Biggs & Collis, 1982), which was recently updated (Collis & Biggs, 1991), is being used as a heuristic to interpret students' responses and the nature of their views about aspects of vision. The essential features of the theory are outlined below but a more detailed summary is included in a related article on children's explanations of vision (Jones, Collis & Watson, 1993).

SOLO TAXONOMY AND MULTI-MODAL FUNCTIONING

The SOLO Taxonomy (Biggs & Collis, 1982) has been used to analyse the structure of children's understanding of mathematical and science concepts. The SOLO theory, involves a five-level cyclical structure for responses within each of five modes of cognitive functioning. The theory postulates that modes of functioning begin to appear sequentially from infancy and each one may remain operational and develop further throughout life.

The modes, and periods of first appearance, are: Sensorimotor (sm: infancy), Ikonic (ik: early childhood to preschool), Concrete Symbolic (cs: childhood to adolescence), Formal (fm: early adulthood), Post Formal (pf: adulthood). They should not be confused with Piagetian Stages.

The sensori-motor and ikonic modes provide their own distinctive forms of knowledge in adult life and are viewed as developing throughout life, and in interaction with other modes. Such co-existence of qualitatively different forms of functioning provides the opportunity for multi-modal learning where learning within one mode is supplemented by experiences and activities in concurrent modes (Collis & Biggs, 1991). The features of these modes are detailed in Table 1.

TABLE 1
DISTINCTIVE FEATURES OF MODES OF COGNITIVE FUNCTIONING IN UPDATED SOLO THEORY

Mode	**Distinctive Features**
Sensorimotor	Functioning is associated with the performance of skilled motor activities.
Ikonic	Relates to that which is perceived or felt directly and which involves the imaging of objects and events.
Concrete symbolic	Involves the use of symbol systems which have referents in the material world and facilitate the communication of declarative knowledge.
Formal and Post Formal	These modes are the most abstract and involve theoretical constructs having no material referents. (They involve both the 'real' and the 'possible')

The cyclical structure for responses within each mode, in order of increasing complexity, features:

- prestructural responses (P) which represent no use of relevant aspects of the mode in question;
- unistructural responses (U) which represent the use of only one relevant aspect of the mode;
- multistructural responses (M) in which several disjoint aspects are processed in sequence;
- relational responses (R) in which several aspects of the mode are related into an integrated whole;
- extended abstract responses (EA) which make use of higher order principles. These may characterise a transition into a new mode of functioning at the unistructural level.

Recent work in mathematics on volume measurement (Campbell, Watson & Collis, 1992) and fractions (Watson, Collis & Campbell, 1991) suggests that there are in fact two major cycles for this kind of content within the concrete symbolic mode. The first shows heavy reliance on the IK mode to develop the concrete concept and the second uses the CS mode as such but utilises ikonic support for problem solving. This example also illustrates multimodal functioning.

OVERVIEW AND METHOD OF THE STUDY

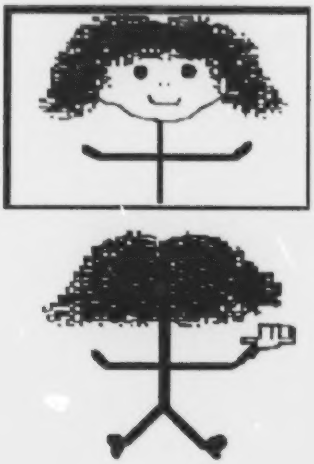
Probing students' understanding about vision

Visual sensing is a dominant part of everyday experience from early childhood and thus the topic of 'sight and light' has much potential for the engagement of children in interesting activities in school science across a wide age range. It also has potential for responses over the range of modes of functioning. Consequently, as a first step in our study, we obtained random samples of scripts from the large ACER questionnaire study (Adams et al., 1990). Children's responses to those items concerning 'light and vision' were re-analysed in terms of their structure according to the SOLO Taxonomy and its recent theoretical developments relating to modes of functioning. On the basis of this analysis (Jones et al., 1993) further questionnaire items have been developed to fill gaps in the available data.

The questionnaire and its trial

A set of nine questionnaire items, in cartoon format, were generated to explore children's beliefs about how people see objects and the role of light in this process. The first item portrayed a four part scenario concerning the use of a torch to see objects in a dark room and the remaining items portrayed common circumstances involving the formation of virtual images by mirrors and mirror-like surfaces.

In order to test the effectiveness of each item to determine children's understanding of the key phenomena, the questionnaire was administered to whole classes from Grades 2 to 10 (n=214) in two suburban schools in Hobart. After an inspection of the written responses, two children from each of Grades 2-6, and three students from Grades 8 and 10 were selected for individual interviews on the basis of their answers to one or more of three items which seemed to prompt the most response. The purpose was to clarify certain written responses and to validate inferences made. The same questionnaire was used as the basis for individual interviews with 12 children from Grades K, Preparatory and One whose verbal responses were recorded on audio tape and later transcribed. For the purposes of this paper Item 3 only, and the analysis of responses to it, will be reported in detail.



The girl is looking into the mirror and puts her right hand up.
Draw how she would see her hand in the mirror.

Why have you drawn it where you have ? Explain.

Fig. 1 Questionnaire Item 3

Questionnaire Item 3

The cartoon sketch in Item 3 (Fig. 1) shows a rear view of a girl looking into a mirror with her right hand raised. Her image is drawn in the mirror except for her hand. The children were asked to draw how she would see her raised hand in the mirror and then to write an explanation of why they drew it where they did.

RESULTS

Children's responses to the item were grouped in terms of their relevance to the question and the degree of complexity of each explanation. A notable finding was that very few explanations included a direct reference to light, either in relation to the object or the mirror. Such responses were restricted to students in Grade 7 and above. Five groups of responses were readily identifiable ranging from those who did not (or stated they could not) offer any explanation, to those whose explanations of a correctly drawn hand made some reference to light. Many students attributed an image reversal property to mirrors to explain the apparent lateral inversion in the perceived image. In the following description of the groups, typical exemplar responses are identified by a code in which the 'v' and 'x' indicate, respectively, correct and incorrect placement of the hand, m and f refer to gender and the last digit is the respondent's grade. Other notations identify particular students.

Group 1. No mechanistic explanation. Whilst a large majority of children in this group drew the hand on the correct side of the image, no one offered an explanation in terms of a mechanism as to why they drew it there. Typical responses were of the following type;

> I'm not sure. x(010f3)
> ...that's how you might have to put it up there because it might have a sore arm. v(112fP)
> Because it's shown there. v(045m3)
> That's where our hands go. x(006f2)
> Because she's looking into it. v(067f4)
> That's what she sees. v(14m10)3
> Because the mirror is showing you how you are standing. v(39m8)

Many were statements of what the world is like, from ones' experience, rather than why it happens the way it does.

Group 2. The hand was drawn correctly and at least one element of an explanation was given. Some made a logical connection between aspects of the girl and her image.

> Because her hand is on the right. v(054m4)
> Because she put up that hand. v(027m3)

Others referred to the concept of reflection, but generally as a name for what is perceived in the mirror, e.g.:

> Because it's a reflection of her. v(093m6)

Some appeared to refer to an elementary type of reflection process, e.g.

> Because when you hold your right hand it reflects. v(003f2)
> The mirror reflects exactly the same thing as you do. v(088m6)
> Because it reflects on the same side. v(033f3)
> Because the mirror is reflecting only the same way it sees it. v(27m7)
> Because the mirror is reflective. v(2m10)

These statements also appear to arise directly from experience of what the world is like, and incorporate mechanistic elements of why it happens the way it does.

Group 3. The hand was drawn, but NOT correctly. These responses appeared to indicate that students had applied the spurious concrete symbolic notion of 'lateral inversion' (i.e. a rule), e.g.

> Because if you put your right hand up it would look like your left hand. x(016f3)
> The mirror reflects the opposite side. x(046f4)
> It reverses your image; so say you had a freckel (sic) on your left, it would still be on your left in the mirror for example. x(086m5)
> Because the mirror reflects. If you put up your right hand in the mirror it would be your left hand because it has been reflected backwards. x(096f6)
> Because if you ... look in a mirror with writing on your clothes it is back to front. x(094m6)
> Because it is reflecting it turns around x(29m7)
> Because the person in the mirror is facing in the opposite direction x(63m9)

Group 4. The hand was drawn correctly and explanations were given which made reference to the apparent lateral inversion by mirrors. It would appear that these children were able to imagine the image as another person (inside the mirror as it were) with a left hand raised, as well as to perceive the image directly from outside the mirror. That is, they were able to handle the two perspectives without confusion even if their concrete symbolic 'rule' about the image reversal property of mirrors is spurious. The basis of their drawings appeared to be their recollection of past visual experiences. Typical responses were as follows.

> Because the reflection is showing it on that side. She can see it on that side but the reflection has it on its left. v(061m4)
> When you look in the mirror like if you write 'toH' in the mirror it would be 'Hot'. v(057m4)
> Because the right becomes left and left becomes right. v(103f6)
> The mirror reflects the image on the wrong side but the right hand in the mirror, because the mirror reflects the right with the right and the same with the left. v(090m6)
> I've drawn it there because when you look in a mirror it gives you a mirror image. It's like looking face to face with yourself. v(081f5)
> If I said to put your right hand up it would be opposite to my right hand but a mirror is different it will be the same side. v(044m3)
> The mirror isn't like a person facing you. v(073m5)
> Because anything in the mirror comes out backwards or opposite because the reflection is facing a different way but normally if it were a real person it would be on the left. v(26f8)
> I have drawn it there because the mirror is reflecting her, it's reversed in a mirror so it looks (like) she's holding her left hand up. v(31f9)

During an interview, a Grade 1 girl gave an extended response which elaborated the insight expressed in the last quotation about images in mirrors:

> There's something not the same about reflection. Because if you have something like a school jumper you can see it back to front. And that's probably left (pointing to the right side of the image) that would be if it was real, and that (pointing) would be right; but that's right and that's left (pointing in reverse). v(115f1)

Group 5. The hand was drawn correctly and explanations mentioned some aspect of the function of light in the perception of a mirror image. It is interesting to note that such responses were rare, and also, only partially consistent with a scientifically acceptable explanation. Light was involved in the production of the image 'in the mirror' or (in the case of one student) in the process by which that image is perceived by the observer.
Responses involving a person to mirror connection were:

> Because the light is reflected straight into the mirror and it's not crossed over. v(6m10)
>
> The cup (sic) is drawn there because once the light hits the girl then goes to the mirror as a reflection which is straight off her body so the picture stays the same. v(33m8)
>
> Because the light rays go in a straight line from girl to mirror, they don't change sides. So if she put up her right hand it would look like the reflection is putting up its left hand. This is a mirror image. v(18m7)

The only response involving a mirror to person connection with light was from a Grade 10 girl:

> When you put your right hand up in front of a mirror, the reflection comes back to you so the light is reflecting off the mirror. v(4f10)

Frequency of responses by group and grade.

The number of children responding in each of the five groups is set out by grade level in Table 2 and is based on a consensus of a group of the authors. The various responses were later associated with ikonic and concrete symbolic SOLO modes of functioning. Table 3 shows the number in each grade who drew the hand correctly on the right hand side of the mirror.

An inspection of the frequency data across grades reveals a change in the distribution of students within the five groups for each grade. This is shown in Figs. 2 and 3 which are graphs of the data from Table 2. The frequency of Group 1 responses across the grades is generally below 25% except for a sharp peak to 47% in Grade 2 (Fig.2). The frequency of Group 2 responses drops off sharply from 67% in Grades K-1, decreasing to 21% in Grade 6, before rising in higher grades. In contrast, Group 3 responses (Fig. 3) have a similar but inverted U-shape change, peaking above 30% during primary grades and generally falling

TABLE 2
PERCENTAGES OF CHILDREN BY GRADE IN EACH
SPECIFIED GROUP OF RESPONSES

	GRADE (Numbers of children are shown in brackets)										
	K-1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
RESPONSE	(12)	(15)	(30)	(23)	(19)	(19)	(25)	(25)	(23)	(23)	(214)
Group 1. Correct or incorrect. No explanation.	25	47	23	22	21	10	4	24	17	17	**20**
Group 2. Hand correct. Experience recalled.	67	33	27	39	21	21	28	28	35	31	**31**
Group 3. Hand incorrect. Image reversal used.	0	13	37	22	32	32	28	12	9	9	**21**
Group 4. Hand correct. Reversal mentioned. Based on experience.	8	0	3	9	21	37	32	24	39	26	**21**
Group 5 Hand correct. Role for light in explanation.	0	0	0	0	0	0	4	4	0	4	**1**
Unclassified.	0	7	10	9	5	0	4	8	0	13	**6**

TABLE 3
PERCENTAGE OF CHILDREN WHO DREW HAND CORRECTLY

GRADE (Numbers of children are shown in brackets)

K-1	2	3	4	5	6	7	8	9	10	Total
92	60	50	61	63	68	64	80	91	74	**69**
(11)	(9)	(15)	(14)	(12)	(13)	(16)	(20)	(21)	(17)	**(148)**

away in late secondary. The percentage of Group 4 responses increases in a smooth curve to 37% in Grade 6 (Fig.3) and varies between 24% and 39% in upper grades. The possible significance of these apparent trends is discussed below. Group 5 responses are restricted to Grades 7-10 and are very infrequent.

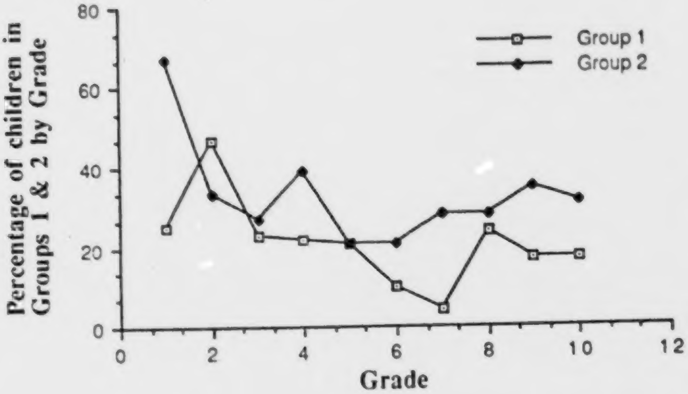


Fig. 2. Percentage of responses within Groups 1 & 2 by grade level

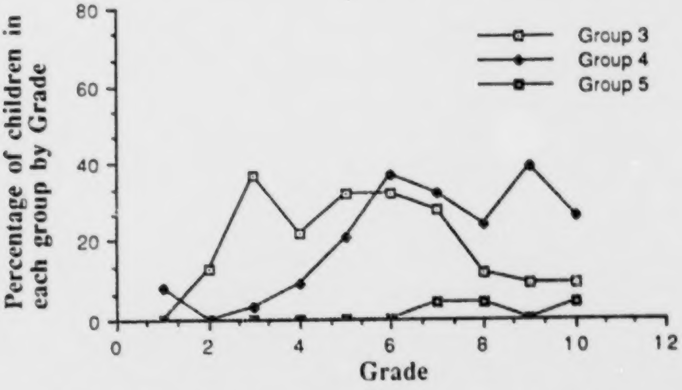


Fig. 3. Percentage of responses within Groups 3 to 5 by grade level

Fig. 4 portrays a U-shaped change in the overall percentage of correct responses. These decline from almost 100% in the K-1 group to 50% in Grade 3 before rising to almost 100% again in Grade 9. The slightly reduced result for Grade 10 is probably uncharacteristic of older students.

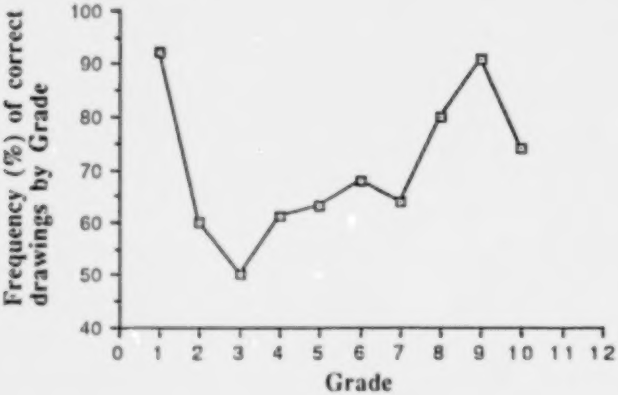


Fig. 4. Frequency of correct hand drawings in each grade level.

DISCUSSION

Although school samples of convenience have been used in this study, it is hypothesised that as age increases there is U-shaped development of children's knowledge and understanding about mirrors (Fig. 4). However, in relation to this, three possibly confounding factors are acknowledged. First, the data comes from an across grade study rather than a longitudinal one, yet it is reasonable to accept it as prima facie evidence with a view to exploring the matter further because such development has been documented before in a number of cognitive domains (Strauss, 1982). Second, as the primary school is relatively small there is a greater chance of variation between nominal grades, although this is reduced somewhat by the fact that all classes above Grade 1 are composite of two grade levels i.e. 2/3, 3/4, 4/5 and 5/6, thus variance due to the different teachers in each grade is reduced. Third, the high success rate in Grades K-1 could be associated with the fact that the children were individually interviewed, however, this is unlikely as the questionnaire was read aloud to all other primary school grades and its wording was used as the basis of conversation for the interviews.

Should the U-shaped success curve for this task be validated one might find a reason for it in the nature of the explanations offered by the children, that is, in relation to the five groups of responses, as follows. It is proposed that the reason why most children in the youngest grades (K-1) had the highest success in drawing the hand correctly is that they relied upon ikonic functioning alone. They readily recalled past visual experience of seeing their image in a mirror and probably had no other knowledge to divert them from its application to answer the simple question. It is the most appropriate mode of functioning in this context. As children get older their developing knowledge can lead to confusion through its inappropriate application. It appears that after Grade 1, children are developing concrete symbolic knowledge about the apparent lateral inversion by mirrors and begin to apply rules such as 'mirrors reverse your image' and 'left becomes right and right becomes left' to answer the question posed. However, this knowledge based on a perception of lateral inversion does not help one explain why the raised right hand appears on the right side of the mirror and, indeed, it leads many to arrive at an incorrect answer particularly in Grade 3 of this sample. Over the successive years an increasing proportion of children appear to revert to ikonic functioning to provide a correct drawing, nevertheless they still make reference to this irrelevant, and scientifically incorrect, concrete symbolic knowledge in their explanations and accept an anomaly with the perceived correct position of the hand. The apparent image reversal phenomenon itself is a dominant perception which appears to affect the personal interpretation of what is seen in the mirrors. It also affects what is recalled of past experience.

Thus, in respect of the children whose answers were allocated to Groups 3 and 4, it is claimed that there is evidence of interaction between concrete symbolic and ikonic modes of functioning, albeit in relation to knowledge about two different aspects of mirrors. Answers resulted from the dominance of the concrete symbolic mode in the case of Group 3, and the ikonic mode in Group 4. Those in the latter group show evidence of having resolved, at least in part, the confusion between two types of functioning. The resolution appears to apply to those in Group 5 also.

It is interesting that none of the explanations of children at primary school, and very few of those at secondary school, involved any direct reference to light, either in relation to the object or the mirror. This is consistent with the findings in a related study by three of the current authors (Jones et al., 1993) that very few Grade 9 students use the idea that light is reflected from objects to explain how one sees them. Many appear to use an alternative framework to explain vision such that objects become bright or 'lit up' and are thus visible. In such ikonic functioning dominated by perception, no object eye connection, in terms of light rays for example, seems to them to be required.

The anomalous drop in success rate from Grade 9 to 10 prompts further thought, in the light of the fact that Grade 10 and not Grade 9 had completed an optics unit dealing with lenses and mirrors. Whereas one might have expected an equal or higher success rate, it might be that the concrete symbolic knowledge related to the unit may have caused a second round of confusion due to interaction between such knowledge and established ikonic knowledge.

One would not expect primary school children to have much knowledge about angles of reflection from mirrors and certainly not of the declarative (concrete symbolic) type. However, one might have expected a few to have referred to intuitive experiences of mirrors to see around corners where object and observer are aligned appropriately with a mirror's surface. Aspects related to this are currently under investigation and two other problem scenarios involving mirrors have been devised to explore the development of related declarative knowledge in the concrete symbolic mode.

CONCLUSION

It appears from the results that different modes of functioning can interfere to produce factually incorrect recollections of experience particularly in the age group 7 to 13 years approximately. Explanations involving light were extremely rare and its importance related to the production of an image 'in the mirror' but not in the perception of that image by the eyes.

As this research proceeds hypotheses will be developed about the order of, and influences on, the development of concepts about light and vision, and typical ages (if any) at which critical shifts in modal functioning might be expected to occur. It is believed that the updated SOLO theory, when applied in relation to specific science topics, may be sufficiently fruitful to contribute to the design of more effective teaching approaches which enhance a student's scientific understanding of the topics and their ability to make higher level responses in appropriate modes.

Acknowledgement

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RESPONSES TO AN INTERACTIVE SCIENCE EXHIBIT IN A SCHOOL SETTING

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ABSTRACT

Unattended science and technology exhibits of both static and operational types have been an integral part of museum displays for many years. More recently interactive exhibits in which observers are encouraged to become part of the system of exhibits have become more common. A study was commenced to explore the impact and potential of low cost, unattended, interactive exhibits set up singly in a normal school classroom without the distractions of a multiplicity of activities as is common in 'science museums'. Three small groups of Grade 5/6 primary school children interacted with a 'Falling Towers' exhibit and their voluntary activities were recorded on videotape for later analysis. Children appeared to state the results of their activity in ways consistent with their expectations rather than with their most recent experience with the exhibit. The responses of girls, boys and mixed groups are reported.

INTRODUCTION

Unattended science and technology exhibits of both static and operational types have been an integral part of museum displays for many years. More recently interactive exhibits in which observers are encouraged to become part of the system of an exhibit, often directly manipulating it, have become more common. The Questacon Science Centre established in Canberra and later its touring Science Circus (Gore, 1985) brought this type of exhibit and stimulating experiences to the attention of the Australian public. Later, this led to the building of the National Science Centre in Canberra which is now a large and popular venue for non-formal science education.

Direct participation in interactive exhibits enables an observer to receive an increased range of sensory input, particularly in relation to tactile sense, thus increasing the potential to experience various phenomena more fully. Such exhibits are designed to engage the mind by creating puzzlement through cognitive conflict which may arise when one's repertoire of images and episodes of natural and contrived phenomena is augmented. Also, they are intended to engage the 'heart' with enjoyable and fascinating events. These experiences with multiple appeals are intended to encourage observers to raise questions, formulate tentative explanations and to test these, where possible, within the constraints of the exhibit. An over-arching objective of this style of museum exhibit is to foster curiosity and the continuance of personal exploration and explanation of physical phenomena. Teachers have organised class visits to interactive exhibits at public facilities such as Questacon and CSIRO Science Centres (Griffin, 1988) to introduce and augment their science teaching in schools. The innovative 'Musbus' (Verrall, 1989) has performed a peripatetic function in Tasmania, Australia, by taking some very high quality exhibits, including interactive ones, to the more isolated schools in the State. 'Musbus' was a mobile extension of the Tasmanian Museum and Art Gallery in conjunction with the Education Department of Tasmania. However, it appears that little has been reported in the major science education journals about these approaches in science teaching or the evaluation of unattended interactive science exhibits.

Martin, Brown and Russell (1991) have evaluated the cognitive gain to primary school students after their interacting with a museum exhibit and the effect of the presence of a demonstrator. Tuckey (1992) showed that children's prior knowledge was an important factor in understanding their responses to an interactive exhibit at a museum. Feher and Rice (1985) and Feher (1991) investigated children's conceptions of light and seeing in the context of interactive museum exhibits and their results were used to modify and enhance exhibit design. Carlisle (1992) has outlined some differences in the roles of Science Centre 'science' and school 'science'. A study of children's framing and refinement of investigable questions in relation to a class visit to a zoo has been described by Symington and Braun (1984).
The present study aimed to explore aspects of the impact and the potential of a low cost, unattended, interactive exhibit set up in a normal school classroom without the distractions of a multiplicity of similar activities common in science museums. The research questions which motivated the study are as follows:

- To what extent can an interactive exhibit assist a teacher of a primary school class in the provision of a worthwhile science program? (e.g. to make a start to teach science; to introduce new topics; to assess or generate interest in a topic.)
- How do children respond to a single, interactive exhibit (with minimal instructions) set up in their own school classroom? (e.g. type of response: questions asked, actions taken; attempts to answer questions; books or people consulted; feelings about, or resulting from, exhibits.)
- What features of an exhibit encourage children to generate questions about phenomena they perceive in the exhibit, and what features facilitate their attempts to find answers?
- What responses appear to be gender related and how might this knowledge help in planning for teaching?

Aspects of the second question are the main focus of this report and they relate to the responses of Grade Six children to an exhibit involving the differential stability of objects resting on a tiltable table. Some preliminary insights related to the other questions are also mentioned in the discussion.

METHOD OF ENQUIRY

Selection and trial of exhibit

It was assumed that an unattended, interactive exhibit for school use needs to be robust, to require little or no re-setting and be not too large for placement in a classroom or adjacent corridor. Furthermore, because the criteria of low cost and relative ease of manufacture and storage are believed to be important, it was decided to replicate a mechanical exhibit seen by one of the authors at a school science resource centre in Bangkok. We call it the 'Falling Towers' exhibit. The device permits the manipulation of a limited number of variables related to the stability of objects at rest.

The 'towers' are two frames welded from 5mm steel rod in the shape of rectangular prisms having square bases of side length 10cm and of height 15cm and 25cm respectively. A steel 'bob' of about 200g mass hangs by a chain down the long axis of each tower from a central hook at the top (Fig. 1).

The position of the bob is adjustable by hooking up more chain or, alternatively, the whole bob and chain can be removed if required. Each upright tower is attached by its own hinge to a base board 60cm x 40cm which is also hinged at one end to a similar sub-base board. The other end of the base can be lifted to any angle so that the towers topple over. A foam

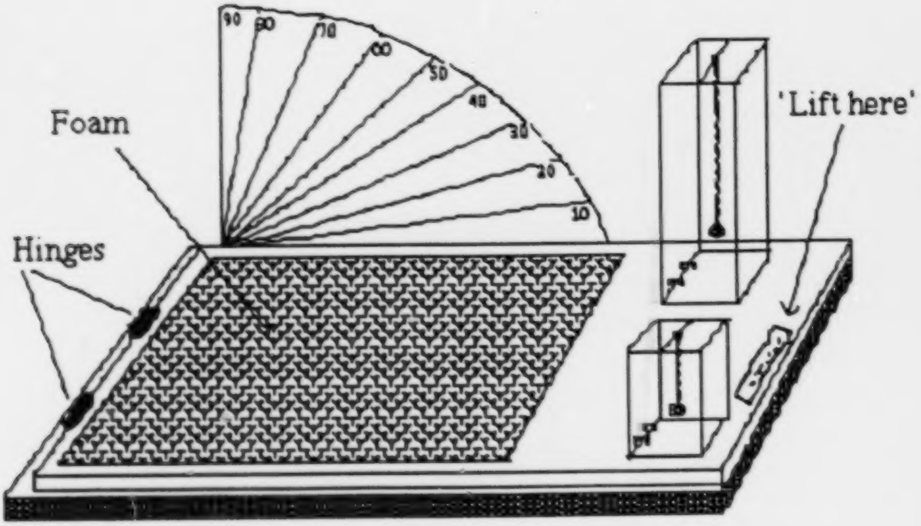

Fig. 1 The Falling Towers exhibit

cushion reduces impact noise on the base board and the hinges at the base of each tower prevent them falling on the floor. A large perspex protractor attached to a long edge of the sub-base board is calibrated at 5° intervals so that angles of tilt can be measured easily. The words 'Lift here' are written at the edge of the tiltable base board.

Development of trial exhibit

The initial version of the exhibit was placed in a primary classroom without comment by the teacher in order to obtain general student reactions and to test its attraction and ruggedness. A sign was placed over it simply stating, 'Try me!' and a notice invited ideas and comments to be written in a notebook supplied. After two weeks a class discussion was held and some suggestions for improving the exhibit were offered by the children. These included 'make it more colourful', 'have removable weights', 'supply a set of instructions' and 'put mirrors on it'. As a result of the trial the original weak nylon suspension cords were replaced with robust chains which could be hooked on and permit the suspension length of each bob to be varied. Also, the lettering of the 'Lift here' sign was increased in size to make it more obvious.

Some properties of the exhibit

As the base board is slowly raised the towers fall at different critical angles with the taller one toppling first. With a full chain length the bob will hang outside the frame before the critical angle is reached. At this angle the centre of gravity (C of G) of the tower system will be vertically above the tower hinge. The presence of the bob and chain shifts the centre of gravity of a tower system from its geometrical centre towards the hook at the top, and if the mass of the bob is relatively high it will swamp the mass of the frame and bring the C of G very close to the top. In common language it would be top heavy and less stable. Without the bob, however, the tower needs to be tilted beyond a larger critical angle to bring the C of G vertically above its base hinge before it falls. Contrary to common intuition the position of the C of G is independent of chain length provided the combined mass of bob and chain remains constant. Unless the base is raised slowly the bobs begin to swing and cause premature instability.

Trial of exhibit and procedures used

The modified exhibit was set up in the 'quiet annexe' of another Grade 5/6 classroom and three purposive samples of students were drawn from the class to interact with the exhibit for 15 minutes, with a minimum of direction. The class teacher was asked to select individuals according to the following criteria on the basis of her judgment of overall student performance at school but individuals were not identified to the researchers in this respect.

* Group 1. Three girls: one average, one each of below and above average performance. (An 'average' student is taken to be one considered by the teacher to perform, generally, in a way expected for the student's grade level.)
* Group 2. Three boys: one average, one each of below and above average.
* Group 3. Two girls and two boys: for each gender pair, one judged by the teacher to be an initiator, and the other a non-initiator, of activity.

The suburban primary school in which this study was carried out draws pupils from a wide range of social backgrounds and includes children from single parent families and migrants from non-English speaking countries. Their parents are variously employed and include manual workers and domestics, technicians, clerks and professionals. The school promotes science in its program, welcomes the contribution of other interested people and has been willing to cooperate in the trial of various ideas.

A video recording was made of each group for later analysis of their physical and cognitive responses, language, explanations and methods of enquiry. Short, written reports were completed by each group on prepared sheets with four statements to prompt open-ended responses ("What we found out", "Did the towers remind you of anything?", "What would you like to change ... so you could explore other ideas?", "Are there any questions ... you would like to have answered?") Children were also invited to design a worksheet to introduce the exhibit to other children in their class who might wish to explore it.

Analysis of the video and written data

The video was viewed many times by the authors to transcribe numerical data and to formulate general global descriptions of group responses to the open-ended exhibit in terms of

* children's conceptualization of tasks and subsequent actions,
* level of cooperation between children,
* significant descriptive phrases and conclusions related to their perceived tasks.

Group reports were brief and included short sentences which merely restated only a few of the remarks recorded on the videotape. Some sketched the apparatus with the pendula swinging.

RESULTS

The verbally stated measurements of angles at which the towers fell are tabulated for each Group in Table 1. Average results from trials by the authors are also shown for comparison in the first column for each tower. The 'all boys' Group did not measure any critical angles and spent most of the time trying to make the towers fall by swinging the pendulum bobs with ever increasing vigour. The other two groups measured critical angles at which towers fell, and

TABLE 1
MEASURED CRITICAL ANGLES (IN DEGREES)
BY GROUP AND TOWER HEIGHT

	SHORT Tower				TALL Tower			
Chain length	Inv*	Girl	Boy	Mixed	Inv*	Girl	Boy	Mixed
LONG	23.5	22	-	22	12.5	13	-	12
SHORTER	23.5	25	-	25	13	15	-	20**
BOB at TOP	23.5	23	-	-	13	15	-	15
NO BOB	27.5	30	-	30	16	16	-	16

* Inv. = Investigators' measurements.

** Verbally stated result of a largely inaccurate reading.

stated them audibly, but they made no records, nor was there any verification of each result by repeated measuring. The global descriptions of each group's responses follow.

Group 1. Three Girls The group commenced immediately to tilt the table and appeared to perceive the task as one of measuring the angles at which the towers begin to fall, which was the designers' intention. Although not waiting for the pendulum bobs to stop swinging, they were gentle in their handling of the exhibit . Their clearly thoughtful and systematic approach led to the chains and bobs being completely removed for the first comparative test. In subsequent tests the length of chain between hook and bob was varied but the whole chain remained intact. Significant features of their cooperative responses were the natural way in which they shared turns to manipulate the exhibit and their apparent willingness to listen to, and to ask questions of, each other with a mutual acceptance of ideas and suggestions. They concluded correctly that "it takes longer (sic) for the shorter frame to fall", and that "with no weight at all it takes longer to fall down".

However, although the stated angles for a half length of chain and for 'bob at the top' are equal for one tower and almost so for the other, one girl concluded incorrectly that: "The higher (the weight) the faster it falls down... with gravity pushing it over". After a link by link shortening of the chain another concluded that "It's not changing very much".
It is interesting to note that, although they measured angles at which an event occurred, they expressed their conclusion in terms of a time variable. It seems that the period of expectancy for the event makes a greater impression than a visual perception of an angle of tilt.

Group 2. Three Boys An initial perception of the task (as one to make the towers to fall by swinging the bobs as pendula) dominated the boys' responses for the full 15 minutes given for the activity. All their changes were variations on this theme. They said "It works !" and "Let's get this one to work" and "Can't you get it to go?". After about 10 minutes they remembered the table tilting facility but made only cursory use of it. In doing so, rather than raise it slowly as suggested on the sign, they tilted it to an arbitrarily chosen angle and continued to swing the bobs as pendula to topple the towers more easily. The boys proceeded in an energetic fashion and one boy was particularly excited as if to test the machine to destruction. In their group conversation they referred to analogous situations such as the leaning tower of Pisa, building wreckers and bell ringing.

Group 3. Mixed (two girls, two boys) This group was initially fairly excited by the exhibit and tended to interrupt one anothers' talk in their enthusiasm to offer comments and ideas to try out on the towers. They showed a playfully erratic approach with much talk but little discussion. The designers' planned purpose was perceived from the outset but was explored to a lesser extent than by the 'all girls' Group 1, and with less refined techniques and systematic procedure. Critical angles were measured with little care, one being grossly inaccurate, and no records were made. Following this, one child concluded about the tall tower: "If more weight's at the top it will fall first" which is inconsistent with their measurements, albeit inaccurate, made immediately before but is in line with everyday experience related to 'top-heaviness'.

Individuals verbalised various small tasks to explore, but there was a distinct lack of closure in their solution before moving on to another task. The activity soon became focussed on a 'retarding' task which they framed by the question: "How long can we keep the towers from falling?" To explore this, the bob was first tied by the chain to rear parts of the structure to affect changes in the 'time to fall'. A second solution was to hook the longer chain to the short tower and drape it over the end of the table to impede its movement.

DISCUSSION

The exhibit appeared to prompt different perceptions as to what might be done with it so that children in each group generated different main problem tasks to be investigated. In each group the 'mind set' associated with an initial problem persisted throughout the time available and influenced most other ideas for exploring its use.

Prior conceptions about related phenomena also appeared to influence children's responses and conclusions. Thus, some of the children appeared to state a result of their activity in a way consistent with their expectations rather than with their most recent experience. For example, as the weight was moved closer to the hook at the top one might expect the tower to be less stable and one to appeal to an everyday concept of 'top heaviness' to explain why. However, this is not the case with this exhibit and the group data do not support it. The location of the centre of gravity of the tower remains unchanged, being independent of chain length. In the absence of written records, expectations were certainly less likely to be challenged. In further work children might, therefore, be encouraged to prepare systematic records in order to justify claims. It is interesting to note that, although both Group 1 and Group 3 measured angles at which an event occurred, they expressed their conclusions in terms of a time variable. It seems that the period of expectancy for an event to occur is more impressive than the visual perception of an angle of tilt.

Whilst no claims can be made here for gender differences in the responses to the exhibit, it is apparent that in this case the 'All-girls' Group were more intellectually active and systematic, they made more quantitative measurements (with greater care) and cooperated better socially in potentially fruitful ways.

The video record provides evidence that most children were engaged both physically and intellectually with the exhibit, although a small minority participated in only one of these ways. Thus, an open-ended, interactive science exhibit set up in a classroom , with few instructions, can engage children from upper primary grades in worthwhile science activities. These may include the generation of investigable questions, the facilitation of cooperative processes to find answers, and the sharing of insights about mechanical phenomena. The latter may become stepping off points for wider discussion of claims and further investigations with teacher support. Such support may reduce the occurrence of early closure upon a solution based on limited or conflicting evidence or a lack of systematic processes.

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DIAGRAM PREDICTION AND HIGHER ORDER STRUCTURES IN MENTAL REPRESENTATION

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ABSTRACT

Predictions of the patterns likely to appear on a weather map diagram one day later than those shown on a given map were drawn by meteorologists and non-meteorologists. Differences in secondary structures of the predicted patterns with respect to the spacing and alignment of graphic elements were consistent with the existence of fundamental differences in mental representation between the subject groups. Lack of expertise in the subject domain of the diagram was associated with the production of patterns containing meteorologically-arbitrary arrangements of graphic elements. It is suggested that science instruction should include explicit consideration of the higher order structures present in diagrams.

INTRODUCTION

Despite the increasing use of visually-oriented instruction with science students, it is not at all certain that illustrations will necessarily fulfil their undoubted potential as instructional resources (Blystone & Dettling, 1990; Constable, Campbell & Brown, 1988; Kindfield, 1993). It is becoming clear from research that the instructional utility of pictorial materials very much depends on how they are processed by the learner (Hegarty & Just, 1993; Willows & Houghton, 1987; Winn, 1991). It seems that highly specialised abstract materials, such as the expository diagrams that are so characteristic of science instruction, are capable of imposing particularly challenging processing demands upon those who lack expertise in the depicted subject domain (Schnotz & Kulhavy, in press). The focus of the present paper is upon an issue that is fundamental to effective diagram processing: that of the underlying mental representation upon which an individual's processing of a diagram is based. The investigation reported here deals with the scientific domain of meteorology and the extent to which higher order knowledge structures are present in meteorologists' and non-meteorologists' mental representation of weather map diagrams. The context of this investigation is a prediction task, a type of task involving processing activity that is central to the scientific enterprise.

Mental representation and domain specific knowledge

Fundamental to the development of an effective interpretation of a diagram is the individual viewer's capacity to construct an appropriate mental representation of the content it depicts. For the purposes of this paper, it will be assumed that construction of a mental representation from a diagram involves the use of both the external graphic markings which comprise the diagram itself and internal knowledge structures within the viewer's mind (Lowe, 1993a). Two important classes of knowledge involved in these structures are (a) domain general knowledge about the visuospatial characteristics of visual information in general and (b) domain specific knowledge about the particular subject matter that is represented by a given diagram (Lowe, 1993b).

Domain general visuospatial knowledge can be employed irrespective of the specific domain involved because it encompasses fundamental graphic aspects of a visual display such as the size, shape and arrangement of the display's component elements. However, the nature of domain specific knowledge is that it is tied to a specific context and so tends not to be applicable across a range of different domains. Further, the acquisition of a substantial body of domain specific knowledge requires some prolonged and intensive form of interaction with the subject domain in question. For example, it might involve extended study of a specific domain or extensive experience within that domain.

Individuals who are classed as 'experts' in their field obviously will possess vast stores of domain specific knowledge, in contrast with 'novices' whose knowledge is much less extensive. However, as well as these quantitative differences in domain specific knowledge, there are also qualitative differences in the way experts' and novices' knowledge is structured (Chi, Glaser & Farr, 1988). In the present research, professional meteorologist subjects were compared with non-meteorologists. Although these two types of subjects do not fit strictly within the generally accepted conception of 'experts' and 'novices' that is used in the expert-novice literature, studies of these two groups to date have revealed many similarities with the findings appearing in that literature (Lowe, 1989, 1993b, in press). Meteorologists and non-meteorologists (rather than experts and novices) have been used in these studies because the differences in their meteorological expertise were considered to parallel more closely the sorts of differences found between science teachers and beginning students of a scientific domain.

Diagrams are widely used to introduce students to key ideas within a domain. However, on the preceding assumptions about the construction of mental representations from diagrams, it appears possible that those who have not undertaken extensive study of a specific domain (such as beginning students) would be limited in this fundamental aspect of diagram interpretation by deficiencies in domain specific knowledge. As a result of these knowledge deficiencies, the very devices that are intended to provide a supportive introduction to a domain may in fact be of limited instructional value to beginning students of that domain. The focus of the present study is upon the qualitative aspects of such knowledge and the way its structural features may influence diagram processing.

Structure in mental representation

There is evidence from a variety of quite different technical domains that experts in a field mentally represent diagrammatic material and similar specialised images characteristic of their domain in an hierarchically structured fashion (Akin, 1986; Deakin & Allard, 1991; Egan & Schwartz, 1979). The higher order relationships embodied in the upper levels of such hierarchical structures can be thought of as implying particular combinations of graphic elements (in one sense, the lowest level building blocks from which a diagram is composed). In the domain of meteorology, many of these higher order relationships have their origin in the physical realities that are depicted in abstract form by the visuospatial relationships among meteorological markings on a weather map. Because physical phenomena are what ultimately determine the meteorological status of a particular geographic region and the changes it will experience, an appreciation of these higher order relationships plays a vital part in the proper interpretation of a weather map diagram. However, the presence of these higher order relationships seems not to be readily apparent to non-meteorologists (Lowe, 1994).

Within a particular graphic display, the visuospatial characteristics of some component elements can have a stronger and more direct impact on our perceptual systems than other elements (Winn, 1993). Graphic elements that either 'stand out' or 'go together' are highly noticeable because of the particular visuospatial relationships in which they are involved. In some cases, as with a cold front symbol, these relationships are deliberately introduced by the author of a diagram to make it easier for the viewer to distinguish different types of information. In other cases, as with the repeated concentric isobars comprising a cyclonic feature, these relationships are simply an artifact of the properties of the natural phenomenon being depicted by the display.

Perceiving important diagram structures

From the point of view of beginning students of a domain trying to comprehend the significant aspects of a diagram, an ideal situation presumably would be to have a clear correspondence between (a) the visuospatial impact of the diagram's graphic elements and (b) the salience those elements have as a feature of the depicted domain. With weather maps, much meteorologically-important information is in fact relatively inconspicuous when considered from a purely visuospatial perspective. The present study is set in the context of one of a number of possible reasons for this lack of visual impact in these diagrams. It concerns situations in which the graphic elements associated with a key meteorological relationship are superficially quite dissimilar or unrelated when considered individually and yet form part of a larger pattern that runs across a number of neighbouring elements when these are considered as a group. For the purposes of this investigation, such embedded patterns will be termed 'secondary structures'. One example of such a situation occurs with a set of meteorological markings that together indicate the presence of a trough structure (an extended band of low pressure that runs across part of a weather map). A trough may encompass several adjacent isobars that are quite different from each other in overall appearance, but which nevertheless possess an embedded similarity because they all contain localised dips or bumps that are appropriately coordinated to constitute a trough axis. In this case, aspects of the visuospatial information certainly correspond with a meteorologically-important structure but these key informational components are masked by the context of superficial differences between the isobars.

A somewhat different example involves not the isobars themselves, but the spacing between them. Isobars show the distribution of atmospheric pressure (adjusted to mean sea level) across the map area and their spatial arrangements reflect the fact that air is a fluid medium. Variation in a property such as pressure through a continuous fluid is necessarily gradual. Both the natural meteorological origin of pressure variations in the atmosphere and the propagation of pressure differences throughout a body of air are highly unlikely to sustain sharp pressure discontinuities. As a consequence, the arrangement of the isobars which marks out the pressure distribution across a weather map should not encompass sudden, arbitrary changes in inter-isobar spacing (gradient). Rather, the broad pattern across a series of isobars should be one of a smooth change of pressure between different pressure centres.

Changes in weather maps with time

The continually altering pattern of weather map markings that occurs over time reflects changes such as the movement of meteorological systems across the area represented by the map or the growth and decay of such systems. These changes in the location or intensity of systems have consequences for the arrangement of isobars that help to mark out the systems. For example, as a system moves, the pressure gradient around its centre tends to travel with it and as a consequence the isobars which depict this system undergo changes in their paths. However, these changes are constrained by factors such as the physical properties of the fluid being represented by the isobars and the nature of the meteorological environment. Thus to compose a meteorologically-correct prediction of a weather map's future state, it is not enough merely to produce a reasonable estimate of the new locations of the main pressure centres. Rather, this must be accompanied by a far more subtle set of adjustments that reflect the nature of the medium involved as well as the influences which determine its local characteristics and structure.

In the present study, subjects were given a weather map diagram showing the meteorological markings present for a particular day and asked to draw their predictions of the meteorological markings that would be present 24 hours later. The spacing of isobars on the original map clearly showed the gradual change of pressure with distance that reflects the fact that air is a fluid medium. In addition, there was a pronounced trough involving several isobars evident on the west coast of Australia. However, neither of these patterns was particularly conspicuous in terms of its purely visuospatial characteristics.

In terms of meteorological realities, both the isobar spacing and the trough that are the focus of this paper should persist over a 24 hour period. The smooth change of isobar spacing with distance is an on-going intrinsic feature of weather maps. The coordination of local segments of isobar curvature that indicates the west coast trough is a structure that gradually waxes and wanes over several days (in association with changes in a large-scale meteorological system known as the subtropical ridge). In order to make a satisfactory prediction of the state of the weather map one day ahead, both these aspects of the isobar pattern need to be drawn in such a way that they are properly constrained by higher level meteorological relations (such as the nature of fluid materials or the nature of the meteorological environment). Because there are no explicit visuospatial cues in a weather map that specially highlight these higher level meteorological relations, such constraint would presumably need to come from an individual's mental representation.

But what might happen if appropriate constraints were not present as part of the individual's internal resources? Without the influence of such constraints, it seems likely that practical factors associated with the mechanics of drawing and considerations which are largely visuospatial would, by default, dominate the construction of the predicted markings. A possible outcome would be a lack of control over the large-scale patterning of isobars and their spacings resulting in the presence of meteorologically-arbitrary variation of these characteristics in the predicted map.

HYPOTHESES

It was expected that in general, there would be little evidence of the influence of domain specific relational constraints upon the secondary features of non-meteorologists' drawn predictions of future weather map markings. This expectation was based upon indications from previous studies that, compared with meteorologists, non-meteorologists' mental representations of weather map diagrams are very much lacking in meteorological relations. Two specific hypotheses advanced as a result of this general expectation were that in drawing the predicted meteorological markings:

* the changes in pressure gradient across the map (as reflected in differences in spacings between adjacent isobars) would be more pronounced for the non-meteorologists than for the meteorologists;

* the coordination of local variations of shape within isobars that indicate a secondary feature (such as a trough axis) would be preserved to a smaller extent for the non-meteorologists than for the meteorologists.

METHOD

Subjects

Sixteen meteorologists were forecasters in the Western Australian Regional Bureau of Meteorology who had from 3 to 30 years of professional experience in their field. Sixteen non-meteorologists were university graduates from a variety of disciplines who were studying for a postgraduate diploma in education. These subjects were without specialist training in meteorology and reported that their main experience with weather maps came from viewing television weather presentations or from the weather section of newspapers.

Materials

Subjects were provided with an A4 sized sheet showing a typical summer weather map diagram for the Australian region (this will be referred to as the 'original' map). In addition to this map showing the meteorological markings (Fig. 1), subjects were given an A4 sheet of tracing paper which was identical to the original except that it showed no meteorological markings (this will be referred to as the 'prediction' map).

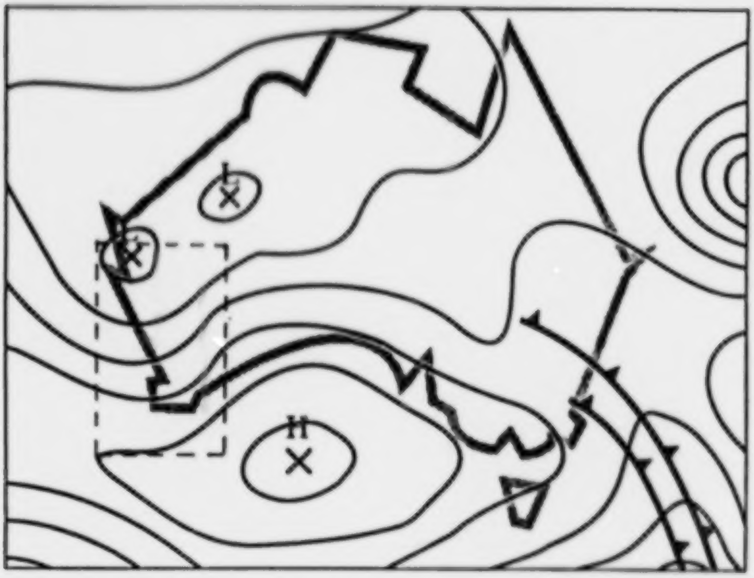

Fig. 1 Original map (boxed area shows west coast troughed isobars)

Procedure

Subjects were given the task of drawing the meteorological markings they thought would be present one full day after those that were depicted on the original map. Each subject performed this task individually with the experimenter and, to facilitate their drawing of the prediction markings, subjects superimposed the prediction map on the original.

Data analysis

Isobar spacing. All prediction maps were digitised and an image processing package used to remove the outline of the map itself so that just the meteorological markings remained. The spacings between isobars were then analysed as follows. A grid consisting of a series of vertical lines at one centimetre intervals was superimposed on the diagram. These grid lines provided axes along which subsequent measurements of isobar spacing were made. Isobar spacing measurements were made within the image processing package using a set of specially developed circular gauges that ranged in diameter from 0.2 cm to 2.0 cm. The measurement technique involved arranging copies of a suitably-sized gauge circles along the vertical grid lines so that these circles snugly fitted between adjacent isobars (Fig. 2).

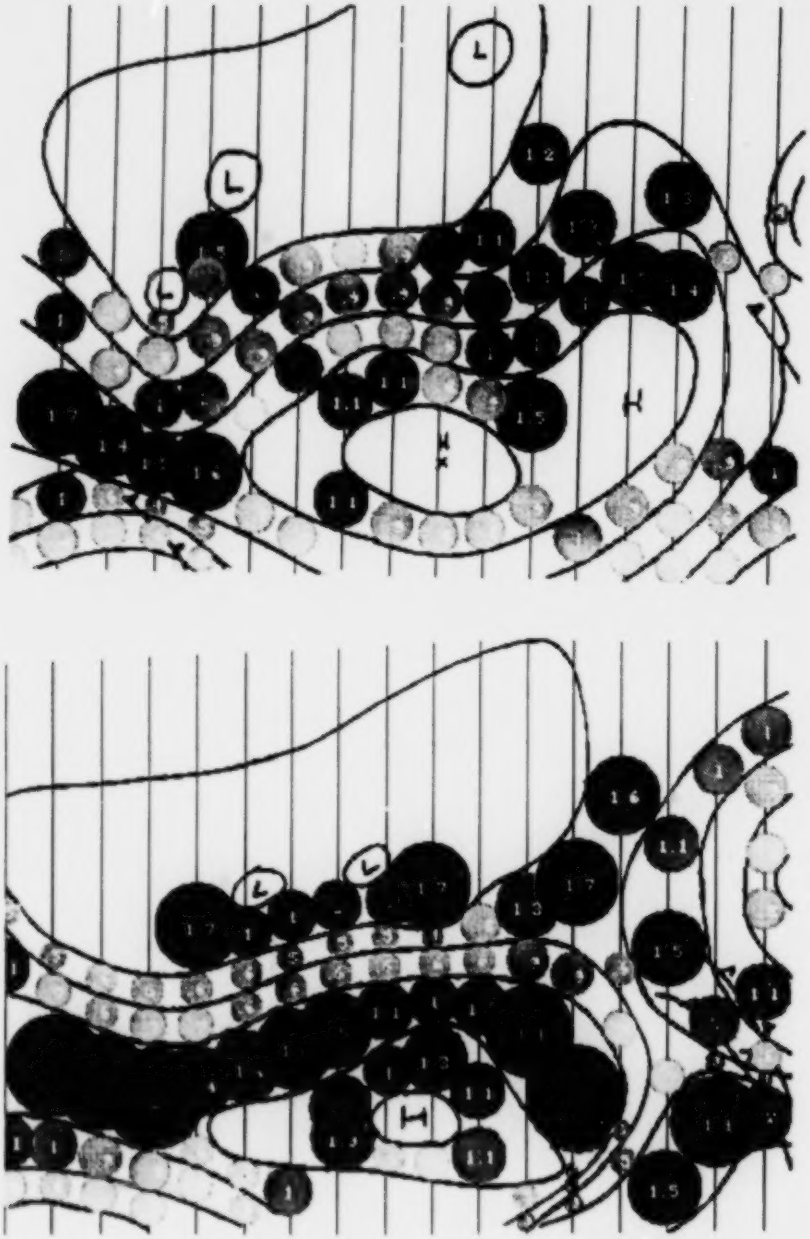
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Fig. 2 Meteorologist (top diagram) and non-meteorologist predictions showing isobar spacing measures.

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Trough axis. The west coast trough was chosen as an index of the degree to which local variations in isobar shape and position (indicating secondary structures) were preserved between original and prediction maps. Assessment of the degree to which the trough axis was preserved was based on examination of segments of five key isobars comprising the trough (Fig. 1). Two judges independently rated the degree of coordination of these isobars on a four point scale ranging from 0 (no discernible coordination) to 3 (a high degree of coordination). Where there was a difference in the two ratings for a particular map, the higher rating was used. The extent to which the depth of the trough changed was also assessed by comparing measurements of the internal angle of the dips in corresponding isobars in the original and prediction maps.

RESULTS

Isobar spacings

For each of the sample sets of isobar spacings corresponding to a vertical grid line, the differences between adjacent isobar spacings were calculated. Overall, these spacing differences ranged from 0.0 to 1.8 cm. The mean of all differences for non-meteorologists (M = .372, SD = .130) was significantly greater than for the meteorologists (M = .311, SD = .051; $t_{(30)}$ = 1.76, $p < .05$, one-tailed) . The meteorologists' differences tend to be clustered more tightly around the smaller values with a maximum value of 1.4 while the non-meteorologists' differences are spread toward the higher values with the range extending to 1.8. The origin of these differences is illustrated in Fig. 2. Moving along the vertical grid lines of this typical non-meteorologist's response reveals a number of sudden and meteorologically-arbitrary changes in spacing. In contrast, a typical meteorologist's response showed the expected gradual change in isobars spacing in these regions.

Trough axes

A Kolmogorov-Smirnov test of the rating data indicated that the axis of the west coast trough was significantly better preserved by the isobars drawn in the meteorologists' prediction maps (M = 2.75, SD = .45) than it was in the non-meteorologists' maps (M = .88, SD = .96; $Z_{(2)}$ = 2.12, $p< .05$). Further, all except one of the meteorologists either preserved the depth of the trough or (as occurred in the majority of cases) made it deeper. The single meteorologist who reduced the trough depth differed from the rest of the subjects in that group by having progressed the subtropical ridge considerably further to the east. Although this amount of movement would be a somewhat unusual occurrence over a 24 hour period, it is certainly well within the bounds of possibility. In such circumstances it would be meteorologically quite reasonable to have the trough wane rather than wax.

In contrast with the persistence or strengthening of the trough structure for the meteorologists, in 50% of the non-meteorologists' prediction maps there was no discernible trough evident. For the remaining half of the non-meteorologist group, such evidence that there was of trough-like structures showed a clear reduction of the trough depth. However, these could not be interpreted as 'meteorologically reasonable' because they were not associated with appropriate corresponding alterations in the rest of the map's structure.

DISCUSSION AND CONCLUSION

The results of this investigation support the two hypotheses advanced above. Both the isobar spacing differences and the evidence regarding the degree to which the secondary structure associated with the trough was preserved are consistent with the non-meteorologists having been subject to fewer representational constraints than the meteorologists when performing this weather map prediction task. Parts of the pressure gradient patterns of the non-meteorologists tended to contain sudden changes of pressure in regions where there was no valid meteorological reason for a change of such magnitude. In addition, there was a lack of consistency amongst these subjects in the way these differences were distributed. In contrast, the meteorologists' spacing differences indicated a generally smooth change of pressure gradient and a pronounced tendency to modulate the spacing gradually according to the nature and proximity of different pressure centres. The tendency of the meteorologists to change local characteristics of isobars to strengthen the troughing contrasts sharply with the way these characteristics appear to have been largely absent in the non-meteorologists. This suggests that the non-meteorologists lacked constraints in their mental representation that would have helped them to retain (or even reinforce) such secondary structure during the processing they performed to produce a prediction map.

Because many of the diagrams used in science instruction can be considered to have various levels of structure, the possibility arises that beginning students of a particular scientific discipline are not automatically aware of this structural sophistication. It appears that although those with little expertise in a technical domain can readily deal with the superficial characteristics of a domain-related diagram (Lowe, 1988a), they may miss its subtleties. Unfortunately, it is often these more subtle aspects which encapsulate key pieces of information that are fundamental to a diagram's domain specific meaning. For example, a student may be perfectly able to produce a superficially convincing diagram of the apparatus for a chemical preparation. However, closer inspection may reveal that it lacks vital relationships between the individual parts of the assembly and as a result the apparatus is incapable of functioning correctly (Lowe, 1988b).

Perhaps instruction that makes use of diagrams as central parts of the teaching-learning activity needs to address various levels of diagram structure in an explicit manner. The mere copying of a diagram is unlikely to reveal these levels to a student who lacks background knowledge of the subject matter depicted. Without knowledge of the potential domain significance of certain details of a particular diagram type, such a student would probably gloss over important visuospatial characteristics of its constituent elements. Further, the processing demands of producing a superficially convincing transcription of the diagram from a textbook or some other 'authorised' version may simply leave too little spare processing capacity available for dealing with higher level concerns (especially where time pressure is involved). When teachers also place great emphasis on the need for neatness, graphic precision and stylistic orthodoxy in the way students draw diagrams, it is perhaps not surprising that their students then pay comparatively little attention to the subtle, but scientifically more important, details.

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PERCEPTIONS OF ASSESSMENT IN A SENIOR PHYSICS CLASS

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Queensland University of Technology

ABSTRACT

Students' responses to assessment tasks are likely to be affected by a range of factors including teaching approaches, the nature of the curriculum, the nature of the assessment task, socialising influences, and perceptions of the teacher's assessment objectives. This paper describes the perceptions of assessment practices held by senior physics students and their teacher in one Brisbane school. The nature and rationale for these practices were inferred from an examination of school documents. Congruences and dissonances between and within these indicators of physics assessment practices in the school are explored, with particular reference to gender.

INTRODUCTION

Traditionally physics has been regarded as a subject that clever boys did and almost all girls did not attempt at school. Forrest (1992) in England, Dekkers and de Laeter (1987) and de Laeter, Malone and Dekkers (1989) in Australia record a marked reluctance for girls to choose physics over an extended period in which there was a corresponding increase in the number of girls choosing to enrol in biology courses. For example, in Queensland in 1987, despite an 8% discrepancy in favour of girls remaining at school from Years 8 to 12 (57% girls to 49% boys), only 28 % of physics students were female. The causes of this phenomenon are many, their identity and relative significance being subject to debate (e.g. Kelly, 1987; Hildebrand, 1989; Rennie & Mottier, 1989; Baker, 1989; Manthorpe, 1982; Stewart, 1991). The prescription for redressing the present gender imbalance in the sciences is uncertain. The differing perceptions held by a range of people (students, teachers, curriculum makers, authors, examiners, etc.) about the nature of physics and what is required to study it successfully provide the focus for the study.

METHOD

The aims were to describe in detail perceptions of physics assessment practices which are held by a class of Year 12 physics students (15 males, 7 females) and their teacher at one high school, and implicit in school documents, and to explore relationships between and within these indicators of current physics assessment practices with particular reference to gender. The school is co-educational, situated in an outer Brisbane suburb where it was established less than ten years ago. The teacher, a middle aged man, is a relatively recent entrant into the teaching profession.

The research planned to utilise a blend of procedures in order to provide multiple perspectives to a rich data set. Relevant school documents were carefully analysed in order to describe the school context and constraints upon the physics program, teachers and students. Such analysis was intended not only to provide insights concerning the dynamic interplay between participants and their environment, but also to establish a framework for the subsequent interviews with students and teachers and the detailed analysis of assessment instruments.

The researcher became a regular observer of, and in some respects an active participant in the activities of the class over a period of two months, attending three of the five lessons each week. Towards the end of this period individual semi-structured interviews of students and the teacher were conducted and tape recorded. Transcripts of these recordings provided the bases for mapping of key components of the interviews in the graphic form presented in following sections. Subsequently the maps of interviews were presented to students, who were invited to indicate their agreement (with a tick), disagreement (x), or neutrality (0) with respect to each proposition displayed. Group discussions with students at various stages throughout the study served to verify and refine the researcher's understanding of the emerging data. A similar procedure was employed to record and subsequently verify the accuracy and interpretation of interviews with the class teacher.

FINDINGS AND DISCUSSION

The school

The school has sought to establish clear statements of its mission and the values and beliefs upon which its program is based. Prominent among these, and listed in the official Student Handbook, are that it strives to provide adequate vocational information to enable students to make occupational choices, and is committed to a program of equal opportunity for all. The school has a policy that students should select subjects for senior school based on what they like and do well. Such choices, made in Year 10, are informed by means of the dedication of several days for the provision of information, support, and counselling. Evening sessions are also provided for parents, one major objective being to convey to them that subjects such as mathematics and physics are not gender-based. It is not until after all students have registered their subject choices for Year 11 that the timetable is constructed, thus ensuring that no student is prevented from taking desired subjects on the basis of a discriminatory line structure in the timetable.

Each senior subject is described in detail in the Senior Studies Handbook. Physics is described as a prerequisite for engineering and science courses, and highly desirable for a range of other university courses. The strong mathematical bias of physics and the fact that a significant part of the study of senior physics involves solving problems using mathematical techniques are emphasised. Based on the outcomes of an initial inspection of school documents, it was decided to include questions in the subsequent interviews of students relating to the nature of physics, their reasons for selecting physics as a senior subject, and whether they could suggest reasons for the ratio of boys to girls in the class. Further, it was decided to ask similar questions of the teacher.

The physics classroom.

All physics lessons were conducted in the physics laboratory, a visually sterile room with stools and fixed benches divided by a central aisle and dominated by a raised demonstration bench. There was generally little equipment in evidence in the laboratory, although basic equipment was available in the attached preparation and store room as required. The girls generally sat together in stable small groups of two or three. Boys also tended to maintain their seating locations but in larger groups of four or five.

During the period of observation, physics lessons typically combined periods of teacher exposition, occasional questioning, student working of set problems, and copying of notes from the chalk board. Although there was a set text, it was not used in any of the lessons observed over a period of two months. Few practical lessons were observed. These were loosely structured, not well resourced with equipment, and the objectives and procedures were apparently not well understood by the students. These lessons involved the formation of large groups, comprising both girls and boys, which invariably failed to complete the intended tasks satisfactorily in the allocated time. Most lessons were disrupted by widespread conversations about non-physics related topics, and the verbal interjections and physical activities of two boys in particular which the teacher seldom challenged effectively. Nevertheless, the overall impression gained by the researcher was that the teacher was well liked and respected by the students as both fair and knowledgeable.

Assessment

At the time of the commencement of the study, the students had completed five formal written senior physics examinations; 49% of the questions on these required students to complete a mathematical calculation or derive a mathematical quantity from a graph. In addition, 34% of the questions required students to recall factual information or interpret factual information which they recalled. While the extent to which examinations structured in this manner are capable of determining students' understanding of physics concepts is debatable, the clear message likely to be gained by the students preparing for them is that they should memorise facts and formulae and practise mathematical problem solving if they aim to achieve high grades.

On the basis of observations of lessons and analysis of the senior physics work program and recent physics examinations, it was decided to include questions in the subsequent interviews with students relating to what they believed they needed to do, and what they thought their teacher expected them to do, in order to achieve a high physics grade. In addition it was decided to ask the teacher what he expected students to do to achieve a high physics grade. Finally questions concerning gender-based differences in responses to other questions posed during the interviews were asked of both students and their teacher. Apart from the questions specifically related to gender-based differences in perceptions, there were no marked differences in the manner in which girls and boys in this class responded to the interviewer. Consequently the responses are presented in an aggregated fashion.

The nature of physics

Fig. 1 reports students' perceptions of physics as a subject. In summary, they see physics as a difficult subject by reputation and by virtue of the ideas with which it deals, and interesting because of its focus on understanding of relevant topics at a somewhat deeper level than junior science. Paradoxically, all students acknowledged that physics can get boring at times.

The physics teacher had little to say about physics as a subject, although he did recognise the interest of some students and the difficulty experienced by non mathematically competent students. His suggestion that students liked the logical nature of physics was not supported by any student. The traditional attraction of physics for tertiary track students was identified by the teacher, but he questioned the accuracy of students' belief that physics inevitably improved their tertiary entrance score. The teacher noted a recent tendency for students with definite goals other than a university course to enrol in physics. One result of this trend, according to the teacher, is a lowering of the average mathematical ability of physics students. He tended to focus on teaching strategies necessary to compensate for the declining mathematical ability of students, and his perceptions of their reasons for choosing to study physics.

Reasons for studying physics.

Fig. 2 summarises the reasons which students gave for their choice of physics, notably because of previous success in mathematics and science and to get a job. Physics is seen as recognised by the teacher. Students and teacher shared a clear understanding of the major reasons for studying senior physics. The next section reveals a similar situation in respect of perceptions of what students have to do in order to achieve a high grade in physics.

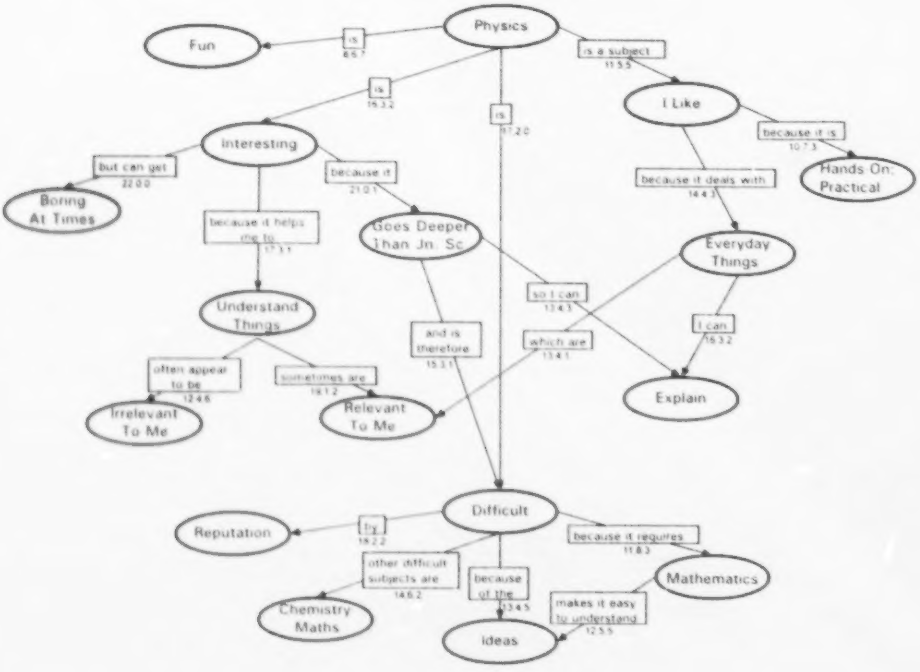
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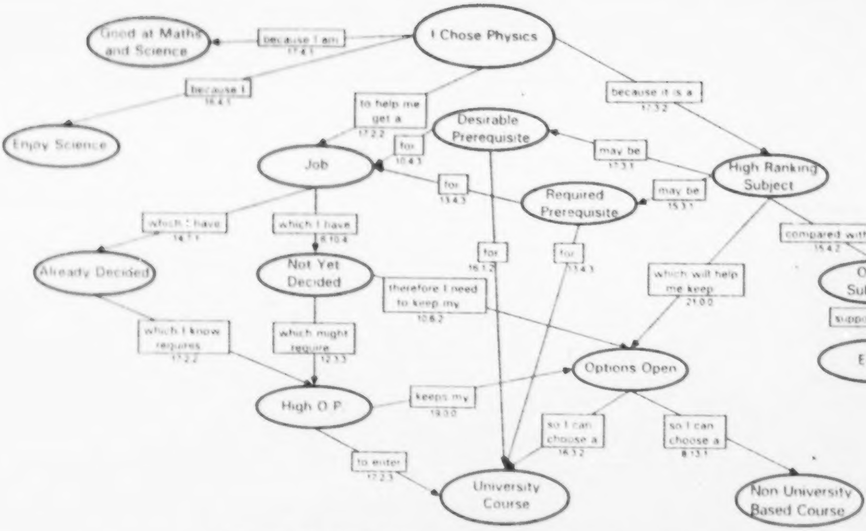
Fig. 1. Students' perceptions of physics
(Numbers represent agreement, disagreement, and neutrality respectively)

Requirements for gaining a high grade in physics

Fig. 3 summarises students' responses to the question "what do you think you need to do to get a high grade in physics?". All students agreed that they needed to work hard so that they would be able to do more than just apply formulae. A two-pronged approach was evident, which involved ensuring that the physics ideas were understood and that many examples were practised. In-class participation was generally regarded by students to be necessary in order to do well in examinations, while completing revision sheets and memorising formulae were very important in preparation for examinations. When asked what they thought their teacher expected them to do to achieve high grades, students not surprisingly all reported an expectation that they should work diligently in class and at home. In their opinion the teacher placed a high premium on paying attention in class and completing set homework and revision sheets.

Fig. 4 presents the rather complex map of sections of the teacher's interviews relating to his expectations of students and the physics program. The principal requirement was that


I Chose Physics
because I am
17.4.1
Good at Maths and Science
because I
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Enjoy Science
to help me get a
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keeps my
19.0.0
Options Open
for
16.1.2
for
13.4.3
which will help me keep
21.0.0
compared with
15.4.2
Other Subjects
supposed to be
12.5.4
Equal
so I can choose a
16.3.2
so I can choose a
8.13.1
to enter
17.2.3
University Course
Non University Based Course

Fig. 2. Students' reasons for choosing physics
(numbers represent agreement, disagreement, and neutrality respectively)

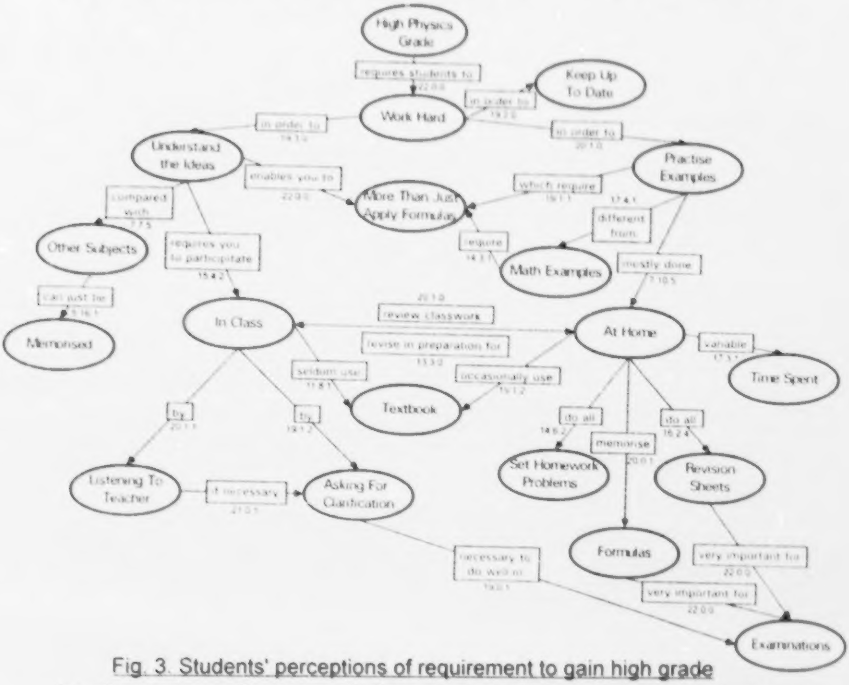
High Physics Grade
requires students to
22.0.0
Work Hard
in order to
19.3.0
Keep Up To Date
in order to
14.3.0
in order to
20.1.0
Understand the Ideas
Practise Examples
enables you to
22.0.0
More Than Just Apply Formulas
which require
19.1.1
17.4.1
different from
Math Examples
require
14.3.1
compared with
7.7.5
Other Subjects
can just be
5.16.1
Memorised
requires you to participate
15.4.2
mostly done
7.10.5
20.1.0
review classwork
revise in preparation for
13.3.0
In Class
At Home
variable
17.3.1
Time Spent
seldom use
11.8.1
Textbook
occasionally use
15.1.2
by
20.1.1
by
19.1.2
do all
14.6.2
memorise
20.0.1
do all
16.2.4
Listening To Teacher
if necessary
21.0.1
Asking For Clarification
Set Homework Problems
Revision Sheets
Formulas
necessary to do well in
19.0.1
very important for
22.0.0
very important for
22.0.0
Examinations

Fig. 3. Students' perceptions of requirement to gain high grade
(numbers represent agreement, disagreement, and neutrality respectively)

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students should understand the subject in order to solve problems. Solving problems requires more than just memorisation of formulae, though that was seen to be important. Only one student referred to the desirability or necessity of taking personal responsibility for ordering or extending the scope of study of physics at home. It appears from the interviews that this concept of appropriate 'student work' closely matched that of the students, in particular that they should work regularly at home and solve problems in preparation for examinations. Because of the nature of the subject and the syllabus, the teacher adopted a highly structured but flexible teaching approach. He believed that the content and structure of the physics course demanded that students rely heavily on the teacher, who knows what is required of them. It appears that this is clearly understood by the students in this class.

Gender-based differences in relation to physics.

It would have been evident to the most casual observer that there were more boys than girls in the physics class involved in this study. It was therefore unexpected that many of the students, when asked why they thought this was so, claimed that they had not noticed or had not thought about it before being asked. Their teacher, however, confirmed that the class did not represent a true cross-section of Year 12, and suggested that boys were more likely to have identified a career option requiring them to study senior physics. Towards the end of their interviews, girls were asked whether they thought that the boys in their class would have responded differently from their responses to earlier questions. Boys were asked a similar question in relation to girls' responses. All of the students maintained that there should not be a difference because ability is a personal characteristic which does not depend on a person's sex. All of the boys agreed with the additional proposition that motivation was an especially important factor. When asked to elaborate, most students referred to the strenuous, and apparently successful, efforts made by staff of the school not only to provide equal opportunity, but also to encourage girls to attempt traditionally male subjects such as physics. Figs. 5 and 6 summarise students' interviews in relation to gender differences.

In contrast to the students' perceptions, their teacher elaborated his view that girls generally outperform boys in junior science because of earlier maturity. The situation is reversed in the senior sciences, where he suggested that boys generally outperform girls, perhaps because of superior intellectual capacity and greater motivation. This class, in the teacher's opinion, was an example of the general trend. The fact that the girls were not achieving markedly different results from the boys was explained by the observation that some boys do not try to do well in physics. Fig. 7 summarises the relevant sections of the teacher's interviews in relation to gender differences.

Students were not in agreement with their teacher in respect of gender differences in ability in their physics class. There were, however, some issues where partial agreement was indicated. For example, girls saw the boys as more disruptive while boys generally regarded the girls as being quieter, which the teacher reported to be obviously the case. Furthermore, girls saw the boys being more involved in the class while some boys suggested that girls sometimes lack self-confidence, which is consistent with the teacher's view of boys as being more forward than the girls.

A range of other, less generally supported comments may indicate that, despite their initial assertions of equality of opportunity and experience, some students sense gender based differences which persist. If so, this would not be an unexpected outcome in light of the teacher's beliefs, especially if similar beliefs are conveyed to the students by other teachers and society in general.

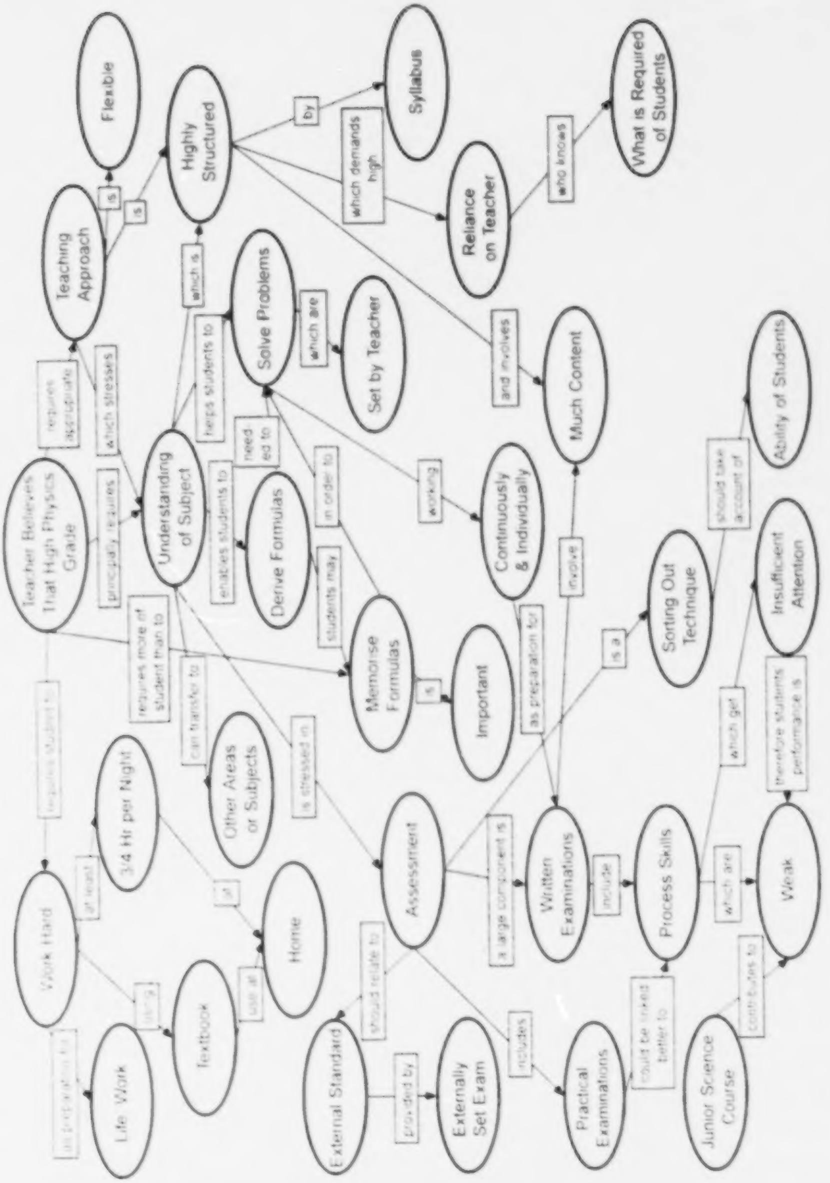
Flexible
Highly Structured
Syllabus
What is Required of Students
Teaching Approach
is
is
by
which demands high
Reliance on Teacher
who knows
which is
Solve Problems
which are
Set by Teacher
requires appropriate
which stresses
helps students to
and involves
Much Content
Ability of Students
Teacher Believes That High Physics Grade
principally requires
Understanding of Subject
needed to
enables students to
Derive Formulas
in order to
working
Continuously & Individually
involve
should take account of
Sorting Out Technique
Insufficient Attention
students may
requires more of student than to
can transfer to
Memorise Formulas
is
Important
as preparation for
is a
which get
therefore students performance is
requires student to
3/4 Hr per Night
Other Areas or Subjects
is stressed in
Assessment
a large component is
Written Examinations
include
Process Skills
which are
Weak
Work Hard
at least
at
Home
using
use at
Textbook
should relate to
includes
could be linked better to
contributes to
as preparation for
Life Work
External Standard
provided by
Externally Set Exam
Practical Examinations
Junior Science Course

Fig. 4. Teacher's perceptions of requirements to gain high physics grade

CONCLUSION

In summary, this study found a high degree of consistency in relation to the perceptions of senior physics held by the students and their teacher, and implicit in school documents. Physics was clearly known to be a demanding and highly mathematical subject useful for earning a high university entrance score, and thereby gaining entry to a preferred course or

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job, or keeping open a range of options. There was also consistency regarding assessment practices in physics. The principal requirement was known to be hard work, aimed at understanding the principles of physics in order to memorise formulae and solve mathematical problems successfully. The gender imbalance in the composition of the physics class was unremarkable for most students, despite the school's well founded equity program. For the teacher, however, the imbalance appeared to be an inevitable result of actual differences which he believed develop between girls and boys with increasing age.

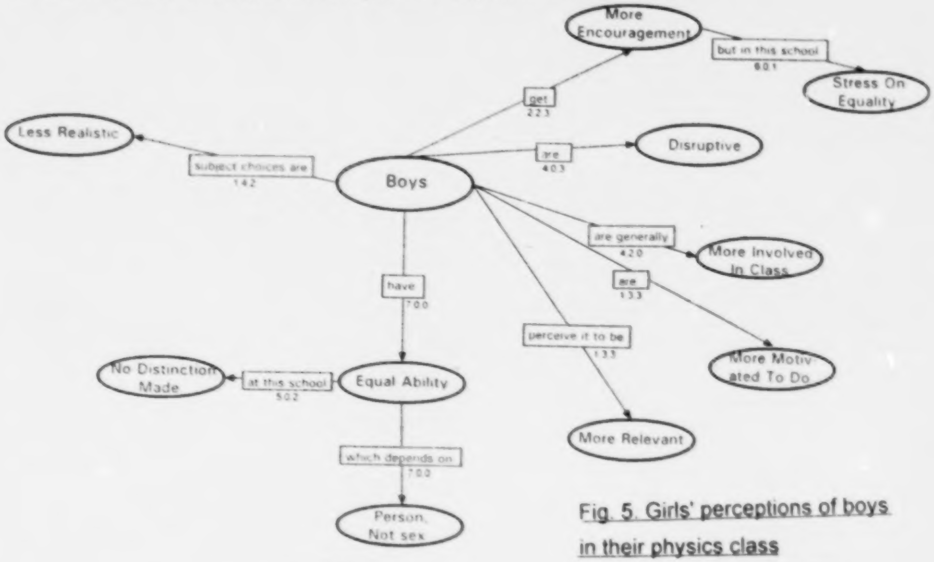
More Encouragement
but in this school
6 0 1
Stress On Equality
get
2 2 3
Less Realistic
subject choices are
1 4 2
Boys
are
4 0 3
Disruptive
are generally
4 2 0
More Involved In Class
are
1 3 3
More Motivated To Do
perceive it to be
1 3 3
More Relevant
have
7 0 0
Equal Ability
at this school
5 0 2
No Distinction Made
which depends on
7 0 0
Person, Not sex

Fig. 5. Girls' perceptions of boys in their physics class

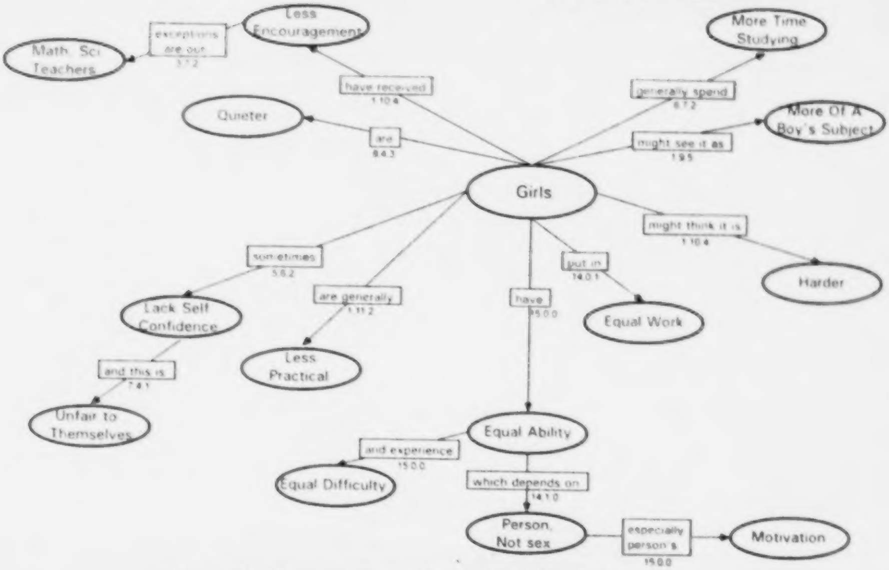
Less Encouragement
exceptions are our
3 7 2
Math. Sci Teachers
have received
1 10 4
Quieter
are
8 4 3
More Time Studying
generally spend
6 7 2
More Of A Boy's Subject
might see it as
1 9 5
Girls
might think it is
1 10 4
Harder
sometimes
5 8 2
Lack Self Confidence
and this is
7 4 1
Unfair to Themselves
are generally
1 11 2
Less Practical
have
15 0 0
put in
14 0 1
Equal Work
Equal Ability
and experience
15 0 0
Equal Difficulty
which depends on
14 1 0
Person, Not sex
especially person's
15 0 0
Motivation

Fig. 6. Boys' perceptions of girls in their physics class
(numbers represent agreement, disagreement, and neutrality respectively)

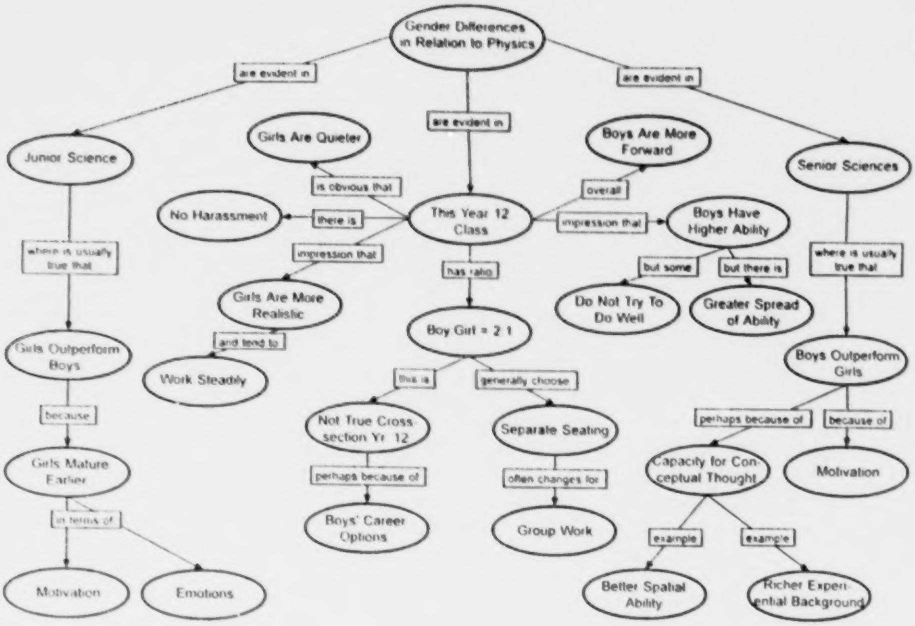
Gender Differences in Relation to Physics
are evident in
are evident in
are evident in
Junior Science
Girls Are Quieter
Boys Are More Forward
Senior Sciences
is obvious that
overall
No Harassment
there is
This Year 12 Class
impression that
Boys Have Higher Ability
where is usually true that
impression that
has ratio
but some
but there is
where is usually true that
Girls Are More Realistic
Do Not Try To Do Well
Greater Spread of Ability
and tend to
Boy Girl = 2:1
Girls Outperform Boys
Work Steadily
Boys Outperform Girls
this is
generally choose
because
perhaps because of
because of
Not True Cross-section Yr 12
Separate Seating
Girls Mature Earlier
Capacity for Conceptual Thought
Motivation
perhaps because of
often changes for
in terms of
Boys' Career Options
Group Work
example
example
Motivation
Emotions
Better Spatial Ability
Richer Experiential Background

Fig. 7. Teacher's perceptions of gender differences in relation to physics

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GENDER INCLUSIVE CURRICULA : A FOCUS ON TWO RESPONSES

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University of Waikato

ABSTRACT

One of the requirements of the New Zealand Curriculum Framework (Ministry of Education, 1993a) is that all curricula developed in New Zealand must be gender inclusive. Developers of the recently released science curriculum, and the draft technology curriculum, have responded to this requirement in different ways. In this paper I discuss a theorisation of the term 'gender inclusive' within national curriculum development generally, and explore and analyse these different responses within the specific context of the science and technology curriculum developments. Particular emphasis is placed on the historical difference between science education and technology education in New Zealand schools, and on the impact theoretical discourses have on the way in which terms such as 'gender inclusive curricula' are conceptualised, and viewed as appropriate, or not, for specific purposes.

INTRODUCTION

In this paper I reflect on the New Zealand Science Curriculum Statement and the draft Technology Curriculum Statement in fundamentally different ways. The comments regarding the science statement are primarily from an analysis and interpretation of the curricula text from *outside* its development practice. The comments regarding the technology statement, however, are primarily from an analysis and interpretation of the text from *within* its development practice as I was the leader of the Girls' and Women's team, and a member of the final editing team on this development. This is significant as underlying concepts and intent are often not clear when stated outside the discourse of their inception. In the case of political documents such as national curricula statements, this is undoubtedly the case, given that those developing the statement do not have ownership of the text produced, and therefore have no control over final editorial changes.

It has been proposed that the curriculum plays a critical role in the maintaining of gendered educational outcomes (Densem & Leahy, 1992). The 1987 Curriculum Review (cited in Baker & Leahy, 1992) advocated change within the curriculum, as well as within the classroom and school, as necessary for the achievement of equality. Therefore it would seem essential to confront the very nature of the curriculum, its development and its implementation, if resultant curricula is to be reflective of the intent of curricula policy. It was in response to this review that the term 'gender inclusive' was incorporated into New Zealand's policy document on curricula: *The New Zealand Curriculum Framework* (Ministry of Education, 1993a).

This document requires that all New Zealand curricula be gender inclusive. As yet no supporting documents have been released to guide developers, which means each development team must make its own decisions about how such a requirement may be met. It was in response to this that my team began its role in the technology curriculum development by theorising the term 'gender inclusive curricula' as positioned within national curriculum development generally. The following section is a summary of this theorisation.

THE CONCEPT OF GENDER INCLUSIVE CURRICULA

Gender inclusiveness can be interpreted as a move away from the liberal feminist base underpinning the previous calls regarding gender. These were in terms of 'equality': equality being constructed as 'girls' and 'boys' 'getting the same'. This discourse employed language focused around concepts such as 'non-sexist educational practice' and 'provision for equal access'. The use of the term 'gender inclusive' in New Zealand's curriculum policy document, reflects a similar trend to that documented in Australia. As stated by Yates (1993, p. 51),

> In Australian policy documents the gradual change in terminology from 'non-sexist' to 'inclusive' is significant here. 'Non-sexist' is commonly interpreted as the absence of a particular form of bias to what is taught, where as 'inclusive' implies a new expansion or transformation of pedagogy, a belief that different groups taking part in schooling have specific qualities which need to be taken into account.

It should be noted however that the concept addressed in this case is one of *inclusiveness* as opposed to *gender inclusiveness*. To be *gender* inclusive - that is to take into account specific needs of groups differentiated by gender, may be interpreted within a radical feminist, or 'feminism of difference' discourse (Grosz, 1990). Within such a discourse, difference between gender categorisation is prioritised. Gender is positioned within a binary notion of female/male (Piussi, 1990), whereby there is suggestion of an essential difference between females and males: that is an inherently female essence as distinct from an inherently male essence. In contrast to this view of gender as representing a differentiating category, Foucault argues that sex/gender is a "category that, rather than causing behaviour and directing desire, is in fact the effect of an historically produced regime of sexuality" (cited in Ferguson, 1991, p.4). Viewed as an effect, rather than a determinative category of being, it would follow that sex/gender must be inherently multiplistic. To assume gender as a static binary means of categorisation, and further, to prioritise such a categorisation over others, would be to deny the complex multiplicity of those who have been labelled 'girl/female' and 'boy/male'. Donna Harraway (cited in Lemert, 1992) and Sandra Harding (1986) write of emphasising all difference in terms of 'fractured identities'. In this rejection of a simplistic essentialist discourse, both sex and gender are conceptualised as social constructions. This perspective is similar to that of many postmodern feminist writers who have looked closely at how useful 'women' is as a concept, and has resulted in a distinctive shift in feminist theorising based on the reconceptualisation of 'women' as "subjects who are multiply organised across positionalities, across several axes and across mutually contradictory discourses and practices" (de Lauretis, 1988, p. 197, cited in Larner, 1993, p. 86).

When employing gender as a prioritised categorisation there is a high risk that characteristics will be attributed as 'belonging' to those individuals who are positioned within this category, leading to the validation, and enhancement, of stereotypical assumptions. In the past, extrapolation from situational observations has resulted in a multitude of stereotypical assumptions which pervade, constrain and construct various discourses. In refusing to permanently prioritise any difference over another, characteristics can never be permanently attributed to that difference, instead identities will be perceived as being "constantly renegotiated and transformed in relation to shifting contexts made up of economic and social conditions, cultural and political institutions and ideologies" (Alcoff, 1988, p. 433, cited in Larner, 1993, p. 86). Using a conceptualisation of curricula which explicitly denies stereotypical categorisations leads to a rejection of the concept of gender inclusiveness as a national curriculum addendum, and rather suggests that *good* curricular theorisation and development will be based upon allowing all voices to be heard in their complexity, and thus will be inclusive of all.

Suggett (1990) discusses the entry of the term 'inclusive' into policy level documents in Australia, and proposes three ways in which curriculum practice may respond to such policy direction. These are by way of: designing new subjects; designing new units for existing subjects; and redesigning existing courses. Suggett argues that the third of these "promises most and is more true to the original intention of the concept" but also points out this is the most difficult option. She acknowledges two major issues which need to be confronted in attempting such a redesigning process: firstly, an issue of 'political control' of curriculum, and secondly the issues concerned with "what inclusive learning or knowledge is - what it might look like?'. Whilst concluding that what an inclusive curriculum might look like is somewhat elusive, she does propose that a redesigning of any subject area within a view of knowledge as "constructed and ideological" could promote critical understanding of the content: to show how knowledge is "historically, culturally, politically and economically located". Such a process of redesigning practice is difficult primarily due to the way in which it necessitates a shift in the way in which that practice is conceptualised.

Such a rejection of the term 'gender inclusive', and replacement with 'inclusive', in national curricular development, does not deny that there may be alternative or specific contexts within which a prioritisation of gender is a powerful political position to assume in order to confront issues of inequity. For example, when responding to practices which make up the social experiences whereby 'girls/women' *are* grouped together, and *as a group*, discriminated against, irrespective of their differences. These positions need not be viewed as contradictory, but, according to Suggett, are "better understood as companions and be seen as complementary". As discussed by Yates (1990), the question is not so much in terms of which is the right position to be bound to, but rather which is of the most use at any one time. It is not therefore suggested that gender inclusive curricula, as a concept, is without merit. Such concepts must be placed within the context of their purpose, and never given a position of universal rightness, whereby they serve to actively constrain that which they attempt to free. The use of the term 'gender inclusive' in *The New Zealand Curriculum Framework* can therefore be interpreted as a means of highlighting an area to be theorised within *particular* curricular developments, thereby attempting to make 'gender' visible whilst challenging it as a means for categorisation and exploring all the implications of doing so.

THE SCIENCE RESPONSE : A VIEW FROM OUTSIDE

The developers of the *Science in the New Zealand Curriculum* statement (Ministry of Education, 1993b) responded to *The New Zealand Curriculum Framework* requirement regarding gender inclusiveness in the following way. Under the *Science For All* section is a statement regarding inclusiveness. "An inclusive curriculum that recognises the perspectives of a particular group of students can enrich education in science for all students." (Ministry of Education, 1993b, p. 11). This is followed by a sub-section on *Girls and Science*, from which it may be deduced that girls are one of the particular groups mentioned. It is this section that will be my primary focus for the remainder of my discussion regarding the science curriculum.

Girls and science

This section begins with an affirmation of girls' ability to achieve, and history of achievement, in science education. This is followed by the observation that many girls, however, choose not to continue in the field of science, both when choosing courses at school and in career options. A rationale for this phenomenon is given by way of girls' perceptions that science is "outside their life experience" and that they "see little use for scientific knowledge and understanding in their future lives" (Ministry of Education, 1993b p. 11). The basis of this rationale is unclear and could be interpreted as problematic depending on how science education itself is conceptualised. Earlier in the curriculum statement, science is described as something that involves "people investigating the living, physical, material, and technological components of their environment and making sense of them in logical and creative ways" (Ministry of Education, 1993b, p. 7). Although it is never stated explicitly as such, there seems to be an underlying assumption that this statement about *science* should form the basis for what *science education* involves. If this interpretation is followed, how is it that science could possibly be perceived by girls to be outside their life experience? Reference is made to the importance of confidence in student success, and a brief critique is given of past science education practice which "often undervalues the contribution of girls, provides unfamiliar contexts for their learning, and fails to develop their confidence in pursuing studies in this area" (p. 11). Having previously affirmed girls' achievement in science, it seems interesting to make this link between confidence and success. How reciprocal is the link: that is, does success increase confidence? Could one assume that if girls are successful they must have had at least some level of confidence? The use of the confidence argument is simplistic and incomplete, and may be seen as confusing what could be interpreted as the 'real' issue here: that there is something 'wrong' with the present *practice* of science education. If this is so, is it the role of a national curriculum statement to focus on, and attempt to provide strategies for, the correction of 'wrongful' practice?

Until this point, the term 'girl' has been used in such a way as to suggest it is an unproblematic categorisation. Acknowledgment is now made to the effect that this category is "non-homogenous", and cultural factors are mentioned as being "inextricably linked" to the concept of gender (p. 11). This is not explained further, except to point out the need to acknowledge the "particular perspectives of Maori and Pacific Island girls" (p. 11). It would appear that 'gender' is being used by the developers as a primary means of categorisation, and gender is a term having meaning within the binary discourse discussed previously. Much of the literature available from the 'girls and science' research in past years has originated from a similar discourse. It has been argued by Gilbert (1994a), that the establishment of a discrete identity for girls within science education was a result of the political strategy deemed most powerful by feminists working in science education at the time: that of making 'girls' visible, and focusing research on this area. Feminist interventions into educational policy, have been, and continue to be, based on the underlying assumption that 'girls' have special needs in science, and that these must be addressed. This was argued in terms of both equality and equity and resulted from a merging of earlier liberal feminist positions, with later radical feminist perspectives. Whilst never intending to be constructed in the negative, the resulting policies and interventions have been interpreted as positioning the 'problem' of girls' reticence toward science education as situated within the 'girls' themselves. This was most commonly perceived to be in the form of a lack of some critical factor(s). Much of the subsequent research has therefore been in terms of establishing what this 'lack' might be and how it might be 'corrected', or alternatively, in 'proving' there is no 'lack' at all (Gilbert, 1994b). The construction of 'girls' as a discrete identity risks attributing characteristics to that identity, which can be highly problematic. The *Girls and Science* section concludes by listing the opportunities which an inclusive curriculum in science can provide to girls:

- learn science that they value;
- develop a range of skills required for successful learning in science;
- use their language strengths and co-operative learning skills;
- express their experiences, concerns, interests and opinions;
- examine the historical and philosophical construction of science;
- view science from a range of perspectives;
- interact in an environment where the language and resource materials used are non-sexist;
- share the teacher's time and attention equitably with boys (pp. 11-12).

This list contains one such attribution, that of "language strengths and co-operative learning skills" being linked to 'girls' by the use of the ownership term 'their'. Whilst the remaining points in this list seem unproblematic with respect to stereotypical assumptions, I argue there is no reason why they should be forwarded in terms of a direct discrete relationship to 'girls'.

Alternative paths?

It would appear the science curriculum is the result of the developers' attempt to construct a gender inclusive curriculum for a learning area by redesigning an existing subject, whilst being acutely aware of the 'problems' in the existing practice of the subject. I propose it was this dual focus which led to the seemingly contradictory statements mentioned above. For example, the basis given for science education is as positioned within a reconceptualised ideal: that is the ideal for the new inclusive learning area called science. The statement regarding girls' perception of science, however, results from perceptions of science as practised within an exclusive science discourse. One means of reconciling these two disparate positions could be to modify the opportunities listed above, and amalgamate them with the corresponding statements of opportunity under *Maori and Science, Students with Special Abilities in Science*, and *Students with special needs and Science*. These could then be listed under an inclusive title, and would then be consistent with, and supportive of, the reconceptualised ideal. A major factor in the exclusive science discourse is that of the commonly held belief that scientific knowledge is in some way neutral, free from social contamination: simply 'the truth', or at least representative of 'the truth', about the world. One modification therefore could be to widen the opportunities listed as "examine the historical and philosophical construction of science", and "view science from a range of perspectives" (p. 11), to focus on *science knowledges* as well as *science practice*. This would serve to encourage a conceptualisation of knowledge as 'constructed and ideological', and would provide opportunity to promote "critical understanding of the content: to show how knowledge is historically, culturally, politically and economically located" (Suggett, 1990).

The context of the development of the science curriculum is however very complex due to the historical nature of science education in New Zealand. It must be recognised that the level of political control apportioned the developers of this curriculum was limited by the very discourse of its development. As discussed above, political control was one of the factors highlighted as important by Suggett (1990). Science as a learning area has a strong and continuing social and political history which has validation in on-going practice. This practice was primarily perceived as separate from this curriculum rewrite. This history therefore would ensure any reconceptualisation of science could well be met by a powerful unified resistance of practising science teachers and others involved in science education. Past practice in science education has discriminated against particular socially constructed groups, one of whom is the group that has been categorised as 'girls'. This resistance may ensure that any attempt to remove notions of discrete categorisation could result in upholding exclusive practice by rendering these same groups invisible. Instead of being interpreted simply as contradictory therefore the science curriculum could be interpreted as an attempt to make visible those 'groups' that past research has shown to have been excluded in science education practice, whilst simultaneously pointing toward an ideal whereby this would no longer be necessary. Perhaps this curriculum statement should therefore be viewed as representing a necessary transient phase of a gender inclusive curriculum, whilst pointing toward the possibility of a future inclusive curriculum achievable in practice.

THE TECHNOLOGY RESPONSE : A VIEW FROM WITHIN

The development of the *Technology in the New Zealand Curriculum* statement offered an opportunity to enter into a redesigning process also involving a need for reconceptualisation.

There were, however, some fundamental differences in this development as compared to the science rewrite. The developers were contracted to produce the first New Zealand draft of a curriculum for a new learning area. This meant they had the political control highlighted as important by Suggett (1990). Although technology has not previously existed as a separate learning area in New Zealand, many subjects have in the past been defined as technological, and could realistically be perceived to fall within the technology framework. Any resistance to a reconceptualisation of technology education would therefore come from those who held concepts of technology as constructed from a wide variety of past practices. Resistance to reconceptualisation could therefore be expected to be somewhat diffuse and less powerful than would be expected from a similar move in science education. This provided a base conducive to initiating a substantial reconceptualisation process, and offered the developers more confidence to remain within the reconceptualised inclusive discourse, rather than being compelled to enter into strategies to counter exclusive practice at the level of a national curriculum statement. Technology is guaranteed validation as a high status learning area by structures already in place: like science, it has been listed as one of the seven "Essential Learning Areas" in the *New Zealand Curriculum Framework*.

These differences led the developers of the draft *Technology in the New Zealand Curriculum* statement to respond to the Curriculum Framework direction toward gender inclusive curricula development, in a distinctly different way. There is no section corresponding to the Science for all, and no sub-section referring to girls and technology. Instead *gender inclusive national curricula* as a concept was theorised and replaced with that of a commitment to *inclusive national curricula*. Three key concepts can be viewed as imperative to this response. They were: the concept of technology, the concept of national curricula, and the concept of knowledge.

The concept of technology

Within the development of the draft technology curriculum, technology was theorised as being inherently inclusive. Technological practice was positioned as being responsive to widely diverse perspectives. These perspectives were viewed not only as valuable to, or 'enriching' for, technology education, but, as an integral part of it. A conceptualisation of technology which relies on diversity, multiple perspectives and the acknowledgment of a wide range of values, was viewed as an effective means of mainstreaming the concept of 'fractured identities'. In this way inclusiveness would be created and validated by the learning area of technology. It would not be possible to practise technology education in an exclusive fashion, and still meet the objectives in the way envisaged by the developers.

The concept of curriculum

Such notions of inclusiveness should extend to that which is unknown, as well as that which is perceived to be known. If curricula are to remain true to this they must move away from fulfilling a prescriptive role, especially in terms of content. The draft *Technology in the New Zealand Curriculum* (Ministry of Education, 1993c) was, in the opinion of my colleague Alister Jones, intended to function as "a framework within which people can operate and think" [interview conducted in September, 1993]. Such a concept of curriculum lies outside traditional curriculum development as practised in New Zealand when 'worthy knowledge' as determined by 'experts', provided the content basis of curricula. Curriculum as conceptualised as a transient framework, would serve to 'open spaces' and support and validate both constructive and deconstructive practice. By the term 'constructive practice' I include the way in which meanings are negotiated for specific concepts, and practices promoted and validated from the discourse as it is understood. By 'deconstructive practice' I refer to a process in which these meanings are challenged and decentred to allow room for alternative meanings and practices. The practices of construction and deconstruction need to be linked and viewed as dependent on one another if such a concept of curriculum development is to be successful in establishing a discourse supportive of inclusive practice. This view gaining credence from those working within postmodernist perspectives in many areas of education. Giroux (1990, p.143) summarises curricula as needing to "embrace the language of critique and the language of possibility". Attempting to combine democratic philosophy and postmodern theories of resistance, he argues against postmodernism as a rejection of modernism, but rather attempts to take from each that which can be considered useful. Lather (1991) also views postmodern approaches as important, with her focus on curricula being considered as a liberatory force. She emphasises the need to deconstruct emancipatory practice, to undergo a "radical reflection on our interpretive frames" (p. 13), rather than simply to reject the emancipatory discourse as no longer appropriate. The focus therefore of curriculum development can no longer be that of determining and providing the most 'worthy knowledge', but must become centred on such things as: whose knowledges have been and continue to be validated as the most worthy, how this has occurred, and how knowledge is experienced and constructed by different people within different discourses.

The concept of knowledge

Cherryholmes (1987) proposes a perspective on knowledge as an interpretation of the world, heavily influenced by power structures and unavoidably inconsistent, fragmented, and unstable. Atkins (1988) rejects that knowledge mirrors reality and proposes that we speak of knowledge as a way of coping with reality. The concept of knowledge as a 'product' of social interactions may be positioned within a social constructionist discourse. Social constructionist positions are many and varied; however, all can be recognised as having moved the focus of ontology away from the individual towards the social i.e. they all work on the basis that "humans are essentially social beings" (Ohlssen, 1991). How a person may act, in which we can include the way in which they construct knowledge, is "located in the public realm" (Ohlssen, 1991). Further to this is the way in which "forms of knowledge can be used to regulate populations by describing, defining and delivering forms of normality and of educability" (Foucault, 1980; cited in Ohlssen, 1991). In this instance, Foucault is referring to his concept of power/knowledge, a concept which has been of major importance in postmodern feminist theory. The *construction* of knowledges within discourse, as well as the way in which knowledges *function* within these same, and other, discourses, provide an important area of focus if we are to allow for discursive practice that is inclusive. These perspectives provide a powerful alternative concept of knowledge from that of the dominant concept, especially as found in schools, that knowledge is stable, consistent in meaning and reflective of reality via neutral/value-free atheoretical investigation. Knowledge as is perceived from a social constructionist/postmodern feminist perspective is never abstract or neutral. By simultaneously holding these ideas of subjectivity and transience, of power relations and social, cultural and personal interactions, a concept of knowledge supportive of inclusive practice is arrived at.

Textual manifestations

The way in which these three concepts merged, formed the theoretical base underpinning the technology curriculum statement and resulted in the following textual manifestations in the final draft curriculum (Ministry of Education, 1993c). Developing the curriculum around a generic core served to support this curriculum as non prescriptive in terms of content. The six learning strands did not represent six subjects or learning areas, but rather an underlying framework on which all learning could be supported. By refusing to prioritise one knowledge base over another, a multiplicity of knowledges could be valued and validated. The objectives in Knowledge strand, specifically the second achievement objective given: 'explore the ideas that contribute to technological developments' (p. 17), is an attempt to represent the concept of knowledge discussed above. This was further developed in the level objectives four to eight (pp. 24, 26, 28, 30, 32) :

- describe, investigate and compare different ideas that influence technology and technological development *e.g. different perspectives, values*
- investigate specific items of technology, identifying underlying ideas involved in their development *e.g. different priorities, who makes decisions and why*
- investigate and explain ideas involved in technology and technological developments *e.g. prioritisation*
- analyse various technologies and technological development *e.g. different world views leading to different prioritisation, decision making processes*
- analyse and critically evaluate ideas underlying technologies and technological development *e.g. different perspectives lead to different prioritisation, exploring decision making processes*

This overall objective, and the four level objectives, allow for the critical analysis of what knowledges have been valued, and undervalued, in the past, and in the present, and why this has been so. They do not actively promote such an undertaking of critique, however, and may well be interpreted in this way only by those who are specifically searching for such 'spaces'.

The inclusion of the Society strand serves to position technological practice firmly within the social matrix of its conception. The two objectives in the Society strand are: (Ministry of Education, 1993c, p.107):

- understand relationships between technology and people in terms of social, cultural, economic, and environmental factors; in the past, present, and likely or preferred future; in local, national, and global settings;
- consider the differing views people have about technology and ways these are influenced by their beliefs, values and ethics.

All technological learning activities should meet objectives from the Knowledge, the Capability and the Society aims. That the Knowledge and Society aims are seen as crucial, rather than optional extras, was imperative for this curriculum to challenge narrow concepts of technology which centre on aspects of capability only. This interlinking was an important feature but is represented in rather a subtle form in the statement's text. Appearing in italics on the Strand objectives pages, (Ministry of Education, 1993c, pp. 17, 35, 53, 71, 89, 107) is the statement : 'Students' experiences should reflect the interlinking nature of the achievement aims and objectives. Learning experiences and assessment examples should include aspects from the knowledge, society, and capability aims.' This statement is no bigger than the rest of the text, and therefore is not particularly noticeable. The Society and Knowledge Aims are further marginalised due to the visual perception promoted by the inclusion of a chart of the strand objectives and level objectives. In this chart the strands are visually presented in such a was as to suggest they are to be of 'equal' consideration - therefore the Knowledge and Society Aims, and corresponding strands, each represent one sixth worth of a learning/assessment example, with the remaining four sixths represented by the four strands of the Capability Aim. This is a major contradiction to the original Aims structure which suggests a weighting of one third for Knowledge, Society and Capability.

CONCLUSION

The *Science in the New Zealand Curriculum* statement (Ministry of Education, 1993b), and the *Technology in the New Zealand Curriculum (draft)*, (Ministry of Education, 1993c), show a different response to the requirement of The *New Zealand Curriculum Framework* (Ministry of

Education, 1993a), that all curricula be gender inclusive. This difference can be interpreted as a resulting from the different discourse each development team was working within. The concept of gender inclusiveness can be interpreted as having been constructed as an appropriate concept to employ in the science curriculum development due to the historical and political positioning of *science* as a subject. This, in conjunction with a liberal/radical feminist theoretical discourse, served to support the inclusion of the referent terms 'girls' and 'boys'. The concept of gender inclusiveness was however constructed as inappropriate for national curricula development within the technology development due to the historical and political positioning of *technology* as a new learning area, and the social constructionist/postmodern feminist theoretical discourse within which that conceptualisation took place. This paper has been an attempt to show the importance of theorising concepts within specific discursive practices, before attributing meaning, purpose and validity to them. In this way, alternative meanings may enable provision for a greater number of strategies to be made available for use in order to move away from exclusive practices of the past.

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KNOWING AND LEARNING ABOUT SCIENCE IN A PRESERVICE SETTING: A NARRATIVE STUDY

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ABSTRACT

This study employs narrative methods to give a holistic view of the experiences of five mature age preservice teachers in a semester unit of science education. The unit was designed to help teachers examine and make explicit their ideas about science and science teaching and consider ways in which they might put those ideas into practice. The pivotal theme, around which the teachers' experiences could be organised, was found to be learning science. The preservice teachers expressed a need for a supportive learning environment in which concepts were built gradually and introduced using concrete examples. Previous science experience was found to be a major influence on the attitudes the participants brought to the present course. A lack of previous experience or negative past experiences were a major cause of anxiety. Gender was also important as it had limited the science experiences available to some participants in the past and continued to influence the way they participated in classes during the semester.

INTRODUCTION

Science is acknowledged as an important part of every young child's education, yet there is much evidence to suggest that science teaching in Australian primary schools is in a parlous state (Department of Employment, Education and Training, 1989). Primary teachers generally seem reluctant to include science as part of their classroom curriculum. This has been attributed to a lack of science background among primary teachers and a negative attitude toward science as a subject (Malcolm, 1989). Indeed, the impact of poor science knowledge on teachers' confidence is seen to be as important a factor as the knowledge itself (Symington, 1980). There is also strong evidence that similar factors contribute to teachers' performance at the preservice level. Weaknesses in science background especially in the physical sciences, negative experiences in secondary school science, the masculine image of science and negative attitudes towards the subject have been identified among preservice students (Appleton, 1991; Skamp, 1989).

A number of Australian studies deal with the attitudes of preservice teachers to science and science teaching. Early studies focussed principally on the impact of the content of preservice science education courses on attitudes. Dooley and Lucas (1981), for example, found little change in attitude after a discipline-based science education unit but found that attitudes toward science teaching improved after a curriculum-based unit. Similar results are reported by Ginns and Foster (1978) and Skamp (1989). In a review of preservice science education courses, Skamp (1988) and Bearlin (1990) found a predominance of curriculum based, learner-centred units emphasising the teaching and learning of science for young children. Most of these units were based on the assumption that low self confidence could be attributed to previous experience of science as a fixed body of knowledge and to gender role socialisation (Bearlin, 1990).

Studies by Walsh, Lynch, Jones and Kerrison (1984), and Walsh and Lynch (1985), gave very different results. These studies found that after participating in a discipline based Open University unit, a greater number of students opted to continue with a science major than in years before the unit was offered. The majority of those who chose the science major believed that increased confidence and renewed interest in science influenced their choice. Increased confidence apparently developed from an increase in the amount and accuracy of teachers' science knowledge (Bearlin, 1990).

These conflicting findings indicate that factors other than the content of units are of importance in building confidence and achieving positive attitudes to science. A number of researchers have made suggestions about the nature of these factors. Some emphasise the need to change preservice teachers' perceptions of the nature of science. Skamp (1989), for example, suggests that traditional science discipline studies could improve science knowledge and attitudes if such studies highlighted the syntactical and substantive structure of science. Carr and Symington (1991) propose that the exploration of processes and concepts from the primary curriculum would improve attitudes to science if they took account of the constructed nature of scientific knowledge. Others emphasise the need for learning environments that could improve both knowledge and attitude to science. Tobin and Garnett (1984) highlighted the importance of concrete activity in workshop situations for preservice teachers with poor abstract reasoning skills and little background in the physical sciences. Bearlin (1990) indicated the need to directly address the masculine image of science by having an explicit feminine perspective integral and formative of all parts of the preparation of primary science teachers.

There have been several attempts to incorporate these issues into science education preservice units emphasising a student centred approach (Appleton, 1992; Hardy, Bearlin & Kirkwood, 1990; Jane, Martin & Tytler, 1991; Skamp, 1989, 1992). In each case, students showed improvements in attitude to science after completing science education units. Significantly, mature age preservice teachers showed the greatest improvement.

Thus in recent years the research on changing attitudes of preservice primary teachers to science and science education has moved from a study of the content of science education units to a more detailed look at other features of successful units. The way in which science units are taught is seen to be particularly significant. Gender-sensitive content and instruction is important as is the need for learning to be student centred. In this case study, these findings have been incorporated into the design of a preservice science education unit taught by the first author of this paper. The study describes the experiences of five mature age preservice teachers during the semester-long unit and describes their unique experiences.

METHOD

A narrative method is employed in this case study. Narrative is seen as a way of seeking out the immediate and local meanings of actions as defined from the actors' point of view (Connelly & Clandinin, 1988). In qualitative research, the self is the instrument that engages the situation and makes sense of it. The way we interpret what we see bears our own signature and provides individual insights (Eisner, 1991). This method is one that acknowledges the constructive position: we make our own experience, we do not simply have it (Guba & Lincoln, 1989). The knowledge to be explored and generated is the resource that lives in the biographies, thoughts and actions of individuals (Eisner, 1991). The findings of the present study will therefore be useful to other educators only in as much as they are able to identify with the issues raised and the experiences described.

The data were collected by the first author working as a lecturer-researcher. Observations, participants' reflective journals and audio-taped unstructured interviews were the principal data sources. Participants' journals contained one entry for each of the twelve weeks of semester and the participants were interviewed on four occasions during this time. Data analysis made use of grounded theory procedures and techniques (Strauss & Corbin, 1990).

FINDINGS

The teachers (Paul, Jean, Susan, Ruth and Ann) volunteered to be part of the study. The science education unit in which they were enrolled had three major modules: one on science process skills, one on the particle theory of matter and one on electricity with an emphasis on constructivist learning experiences. As part of the unit, participants were asked to examine the various influences on their attitudes toward science and on their confidence as science students. Participants were also asked to reflect on their learning experiences and learning needs during the unit. Making sense of the participants' experiences leads to a set of themes and sub-themes which provide some insights into the knowledge and learning of these preservice teachers. The major themes are learning science: in the past, and in the preservice setting.

Learning science: in the past

Each of the teachers had studied science at secondary school. Paul had studied physical sciences during his final years of school. Ann, Jean and Susan studied biological science at senior secondary, while Ruth had last studied science in lower secondary. All participants except Paul expressed some initial negativity towards studying science. The first journal entries and interviews provide evidence of the importance of previous science experience in shaping the attitudes of the participants to the study of science. Two sub-themes emerge: confidence and familiarity, and difficulty and masculinity.

Confidence and familiarity. The stories of Paul and Ruth illustrate the range of past experiences with school science. Paul studied Year 12 physics and chemistry in 1961 in a single sex school. He described the science teacher as "hopeless" but explained that all the boys at his school studied physics and chemistry. Paul drew on these high school experiences and his training in radio and television servicing in what he describes as the "early days of TV", as a means of recognising some familiar terms in the present science education course:

> I went to Senior but I finished that in 1961 when I took chemistry and physics. It was so long ago, it's shaded back into the distance but I'm quite familiar with what you are doing [in the science education course] with bunsen burners and flasks and all the equipment you are using [Interview]

This idea of familiarity often occurred in dialogue with Paul and he built on this foundation a feeling of confidence and enthusiasm for science and science teaching throughout the course. The following is an excerpt from the fourth interview, during the final week of lectures.

> I am enjoying the science. It's something that I have covered before as you know, probably some of the terminology and some of the little ways that things are approached are a little bit different to the way I am used to, but adaptation, you know... I'm used to using more terminology and going into more depth. So to me it's a surface thing but you've got to start at the beginning as they say. Having done two years servicing and all of that sort of stuff... I notice when you said in the lecture today, don't use EMF and voltage and amps and all those sort of things, they're the things that I probably have to pull myself up and not use those things. With those bulbs and the batteries, you were saying you were using 6.2 Volt bulbs and my mind then thought well, if I had the wattage of the bulb, I could work out the resistance and I could tell you how much voltage was left in that just by using the EIR formula. I could sort of work out how much almost mentally, how much power was left in the battery. Those sorts of things come into my mind which wouldn't come into others I guess. So I'm like that. I am enjoying science, it's great.

Evidently, Paul did not always clearly remember the science content of his school days, but the fact that he recalled covering some of the concepts before was a significant boost to his confidence. In the same interview he went on to say:

> You know it's a strange thing, what's emerging for me personally is that I'm developing an interest in science to the extent that this could be the thing. You know you have a "thing".

Difficulty and Masculinity. In contrast to Paul, Ruth completed her schooling at the end of Year 10 at a single sex school. In the first interview, she outlined some of her school experiences in science and her attitude towards the subject:

> I remember walking into the lab. in Year 8 and I just thought, "What's all this", you know. And I found it interesting, I loved the experiments and things, but, they weren't explained properly or something. I just thought, "It's too hard, she's not explaining it properly and I don't understand it". You sort of get this negative feeling about it. You think, "It's not for me, it's too hard". If I wanted to [go beyond Year 10], , I could have. But because of that, because of no explanation, and even in the exams, they were just, I don't know, if I remember right, it was just the results of things and if you don't understand them how do you know the results. Do you know what I'm saying? And it was just really smart, intelligent people do science! Normal people don't.

It seemed to have been more difficult for Ruth to consider studying science than for Paul. Rather than being the "thing to do", as in Paul's school, science in Ruth's school was reserved for the "intelligent people". The difficulty of science also featured in the past experiences of the other participants. Some teachers experienced the gendered nature of the subject more directly than Ruth and Paul. Susan attended a co-educational school and described the influence of gender on her subject choice in her first journal entry:

> In those days specialised science subjects such as physics and chemistry (both in junior and senior years) were geared more to the males than the females. Females predominantly did home economics which ran at the same time as did these science subjects.

Ann did not tell directly of gender bias in subject selection. However, in her first interview, she told of her difficulties with physical science, the influence of her past experiences on her tertiary studies and the effect on her own children. She also mentioned how a lack of science knowledge brings a sense of inferiority.

> At secondary school I didn't do chemistry and physics because I found it too difficult and I am not a mathematician ... and so I couldn't fulfil my dream of being a marine biologist because I didn't have the other subjects, but I did study biology up to and including first year tertiary and then again I found the mathematics and stuff getting too hard for me... [The current unit is] interesting because it's so many years since I have had anything to do with bunsen burners and just plain elementary scientific facts, I mean I am very ignorant on basic science, I really am. I don't know much about things expanding when they get hot. I sort of know it in theory but I have never worried applying it to things. The bits of theory we got at school were never connected to real life, ... and so science to me has always been a subject in some other realm. And it's always annoyed me that I didn't understand how things worked. You know, it makes you feel a bit inferior, ... And my son I feel is a bit awkward with because I can't help him understand it very much because I don't have a mechanical mind and I don't know anything about chemistry worth knowing and so he just doesn't get exposed to things.

Jean has a science background similar to that of Susan and Ann and she also attended a co-educational school. In her first interview, she related the influence of a teacher in perpetuating the idea that science is both difficult and male.

> In Year 11, I chose biology and half way through Year 11 I moved schools. I kept on with the biology but it was a different curriculum here, so that kind of threw me and then the teacher wasn't real great so that completely threw me - it turned me off it. The teacher I had here was very young and he really enjoyed humiliating his students. Most people were very frightened to even attempt to answer his questions because he would just annihilate them. And he very much favoured the boys in the class too... He wouldn't humiliate them as much and really it was just obvious he favoured them. He would praise them - they were always the ones chosen to do things and if anybody was picked out as knowing things it was always the boys. Some of [the girls] tried [to join in], not a lot. The ones that were obviously very intelligent anyway. I think probably more so he favoured the more intelligent people more than the ones who were average or under, if they didn't understand he just didn't have any time for them...

Paul's school studies in science, although well in the past, helped him to feel familiar with terminology and equipment. Ann, Susan and Jean had all been influenced in some way by the idea that science subjects were more appropriate for male students than female students. Ruth did not associate science with males but did see it as a subject for the very intelligent. All four of the females had experienced science as being a difficult subject. They did not approach the science education unit with the same confidence as Paul.

Learning science: in the preservice setting

As the study progressed, the teachers reflected on aspects of their current learning in the science education unit, which they compared and contrasted with their experience in learning science in the past. Several sub-themes emerged: supportive environment, construction of knowledge, pace of learning, working with others, concrete experience and reinforcement.

Supportive Environment. Jean's account of learning science in the past described the absence of a supportive learning environment as well as the notion that science was difficult and masculine. At the end of her first journal entry, Jean projected her thoughts into the future to describe the learning environment she desires for her own classroom:

> I am looking forward to trying again with science and taking it out to the schools. My students will benefit from my experience, as no matter how simple or off the track their answers may seem I will find some way of praising and encouraging them and hopefully never stifle their want to learn.

Both Jean and Ann were embarrassed at times by their lack of science knowledge. More than most, they appreciated the freedom to ask questions in the science education unit. In Jean's first interview she commented:

> I think probably because of my background in science, the first workshop I was really a bit hesitant to answer any questions in case they were wrong. But the second workshop I really enjoyed that last week. I really liked that and felt more confident and happy. I think it's because we know you now and you're not going to turn around and say "You're mad, you're wrong". Like you said you're there to make it so that nobody is wrong, so I don't think it made anybody feel bad.

In a journal entry Jean shared the following insight into her current learning about science:

> I think I started this journal off by saying that I take a lot of things for granted and don't stop to think about how they work. Well batteries fall into this category. I didn't know they produced electricity. I knew they produced power of some description, but never thought of it as electricity. (This makes me sound stupid, and I wouldn't have included it if I wasn't involved in the case study.)

Construction of Knowledge. Ann talked about questioning in her second interview. She detected a learner sensitive approach in most of her curriculum subjects in the second year of the university course:

> One of the things I find really good at the moment is the acceptance of what most people would consider silly questions, you know. Because you feel as though there is an obligation on the part of other people to get into your concept map. If they're supposed to be teaching you, that's what they should do. Just like you would extend that right to children yourself later, surely you should have that yourself for the sake of your learning, you know, and so its making me feel a lot more courageous... I find that it sort of creates an atmosphere of freedom, and a lot of students, at first we felt very inhibited, and we're getting less inhibited, and I think that especially, the older ones, the younger ones I think are a little bit slower to do that or they already know, ...

Ruth had some interesting things to say about a unit on electricity that used a constructivist approach to learning. Some preservice teachers enjoyed it, while others found it very difficult. The latter group seemed to have a transmissive view of learning and believed that their time was being wasted because they couldn't get the correct answers. They saw the "correct answers" as what they "needed to know". In the fourth interview, Ruth talked about how she was finding the unit:

> I liked the approach. I wrote that in my reflection. Like you said "Just do it like as though you know no information," which I didn't, it's the perfect way to learn I think... It's perfect in the way you're doing it because the people who don't know, like me, it's giving us a chance to, you know, go through it and everything. There's a lot of younger kids who don't understand it either. You know, its not only the mature age is it? No. Actually, I'm surprised at that. Because I think, "Gosh they just finished school a few years ago" and most of them would probably do science...

Ruth was comfortable with starting to build understanding by changing her own explanations where appropriate. She believed that this method allowed her to be on a more equal footing with students who had done science before, to "have a chance". Ruth needed to develop new ideas slowly and this style of learning is much slower than one based on a more direct teaching method.

Pace of Learning. The pace at which new ideas were presented was of particular importance to three of the preservice teachers studied. They emphasised the need for a slow introduction of new ideas. Ruth contrasted her experiences in the hands-on workshops with science in secondary school. In her first interview she made the following comment:

> I think it's better now because you're getting into and doing it slow like you said and explaining things and then they observe and why does that happen, why is this growing, why? why? Its all the why's isn't it? I think it's better whereas in high school it was terrible. I hated science.

Ruth had difficulty with the introduction of new terms in a lecture on the particle model for matter. In her journal that week Ruth wrote:

> In this lecture I was completely lost. I could not understand anything that was being talked about. Totally lost, therefore cannot make or write a good reflection. Perhaps less content of this nature, in one lecture would help me i.e. if there was less content more time could be spent on explaining terms etc.

Ruth was happier in the supportive atmosphere of a workshop class on freezing of liquids even though the concepts were more difficult than those introduced in the lecture. In her journal she wrote out an appropriate explanation of the behaviour of matter during change of state in her own words and then said:

> I was a little confused at the end of the workshop and had to go and think about all that I had experienced. A lot of practice might make me feel more confident when I speak about the particle model and its change of state.

It would seem to be a more hopeful entry than the previous comment. Although the work was difficult for her she was not "completely lost". Ruth was unfamiliar with science concepts and terminology and lacked confidence when they were introduced. The group situation was helpful to her in dealing with new and abstract information.

Working with Others. Some participants, however, experienced difficulty with group work. Jean described her interaction with a male member of her group during the module on electricity.

> A few of [the activities] I've tried out because I have to find out for myself "why?". I like to prove things... Well at the moment it's kind of one person does [the activities]. The actual hands-on... He kind of romps away, romps ahead and you can't see step by step what's happening because you might be writing down something, it's still going and you say "Hang on" but it still keeps going... I was also surprised to find that I actually knew more than I thought I did when I got into that group. And I knew more than the one that was setting everything up and that so... This other person is kind of hard to control. If they're going to do something they're going to do it and that's it! I gave up in the end and just wrote down my own answers and let them go which wasn't really group work.

A similar situation may have occurred in Paul's group. A female student, who was a member of Paul's group but not part of the case study, made the following journal entry after the first week's work on electricity:

> At times he [Paul] seemed to dominate our activities and discussion. The best way I found to deal with this, was to challenge his answers and get him to reword his sometimes complex and professional answers. It helped the other members of our group to hear his views, but we needed to consciously make him explain his answers in simple terms. Dynamics in our group were quite interesting. I discovered I wasn't happy just to sit back and let someone show me how it's done. I was curious and wanted to try things for my self.

This student approached her problem in a different way from Jean. The use of "we" may suggest that she had support from other group members when she insisted on taking an active role. Paul himself acknowledged his respect for this female student in the third interview when he was asked about group work.

> The [group] is OK, they're OK. [The student concerned] is very good. She's very clever and um, the other two, they're OK... [The student concerned] might be a little bit ahead of us. She's very quick on the uptake. She's quite clever.

In Jean's case, she thought that she knew more than "the one setting everything up". However, unlike the female teacher in Paul's group, she did not assert herself. The male members of the group seemed to be unaware of her ability. In both Paul's and Jean's groups, gender seems to have influenced the quality of learning for the participants. Group work, while capable of providing a differential pace for learning and a supportive environment, requires that members have appropriate social skills so that they fully participate and allow others to do so.

Concrete Experience. One thread common to all accounts was the importance of actually handling the equipment and carrying out activities. Some preservice teachers had difficulty with abstract thought. They often commented on the importance of concrete experience in their learning. In the first interview, and in his journal, Paul described his secondary school experiences. These would not have been of benefit to him if the picture he painted of himself as a learner was true.

> In lectures we are given an overview and in the prac. we are given the opportunity to try for ourselves. This a total contrast to my remembrances of science classes when I was at school. In those days we just watched the teacher demonstrate after reading the procedure from a text book. (Journal)

In the science education unit, Paul experienced some difficulty in understanding the process skill of controlling variables. In the third interview, he described himself as a visual, hands-on person.

> I'm not much good with abstracts. I've got as much talent in an abstract area as a grasshopper I'd say... In mathematics, I find I like geometry better than I like the ordinary mathematics because it's something you can play with whereas with ordinary mathematics, you can't... I would say my personality says "Yeah", more visual or hands on more than thinking, but then some things you've got to sort of imagine it in your mind and you've got to work them out, but then I like to visualise them so I suppose I'm a visual person.

In his journal in week five, Paul also wrote of his concern about controlling variables.

> At the present time I am experiencing slight difficulty in conceptualising the idea of "variables". I understand the experiment with candles but at this time I feel I would not be able to confidently devise an entirely original experiment to illustrate manipulated, responding and constant variables all at the same time.

Ruth had similar difficulties when it came to conceptualising a controlled experiment. Like Paul, she had difficulty with a revision lecture where students were asked to name variables in investigations they had not actually carried out. She had already noted in her journal that she would be confident in carrying out an investigation that involved controlling variables, because she had actually participated in such an activity in a workshop. In the following extract from the second interview, Ruth discussed the theoretical investigations and stated her preference for hands-on work in workshops and visual aids in lectures.

> Just like for instance, what was one of them, like, can you pick the controlling variable or something like that? You went through a series of questions that were on paper. And seeing them down, I couldn't work it out and it sort of worried me... Whereas when I am doing it in the workshop, I think "This is good. I enjoy this. I love doing this".

In journal entries, Ruth described her preference for visual and hands-on learning. The following extracts tell of her experiences in a lecture on chemical change.

> This was the most interesting and demonstrative lecture in science that I have attended. Why did I think this? Not only was it informative but every step was shown by example. The egg shell placed in vinegar there to be seen and to see what happens e.g. bubbles forming. The iodine placed on the bread, visually perfect to demonstrate chemical change. The balloon placed on the top of the flask which contained vinegar and a tea bag full of baking soda clearly demonstrated that when ingredients mixed they form a gas and that the chemical substance alters but the mass remains the same... This lecture kept me alert, stimulated my visual sense and most importantly demonstrated what was meant by compounds etc.

Jean and Susan made similar comments in their journals about the helpfulness of visual aids and hands-on experience.

> I was pleased to hear in the lecture that for concept development to take place children need hands-on activities. I have always believed that anyone learns best through hands-on experience, and being in a supportive, positive atmosphere. This concept not only applies to children, but everyone. I find I get a better understanding from watching a demonstration or hands on experience. (Jean)

> I found this week's lecture and workshop more interesting than last week's, probably because the ideas were not hard to grasp. Again I liked the mini experiments in the lecture, as I feel they show us a lot more information than if words were just used... After a hesitant start, I then went on to find this workshop quite interesting much to my surprise. I had always thought learning about electricity would be boring. I feel the main contributing factor in making this lesson interesting was that we could actually manipulate the batteries and bulbs ourselves. This allows the activity to mean more to us personally. (Susan)

Reinforcement. Many of the preservice teachers had difficulty with abstract thought. They preferred to carry out activities and to watch demonstrations. Hands-on activity provided motivation, as Susan suggested, but many science concepts are abstract and much thought is required in their development. Some participants found self-paced learning materials that they could use at home to be of great benefit in understanding concepts. In one of the interviews, Jean talked about how she managed to adapt what she learned about the introduction of new terminology to her own lesson planning:

> [Repetition] is really good for people like me who don't know what you're talking about and if you grasp one concept then they repeat that and introduce one more and repeat them and introduce a new one. They're repeating the old ones and just slowly introducing something new... I'm doing a maths lesson this week on tessellations and I actually won't introduce that word until the conclusion of the lesson. Just patterns and tiling then right at the very end I'll introduce that word.

Some teachers needed more time to understand concepts than others. For example, Susan found a workshop on light to have too many activities. This workshop was not as directed as others. The activities were arranged around the laboratory with accompanying instructions and questions, allowing for self pacing. Many of the preservice teachers finished early, but Susan and her partner needed extra time. They did not leave a station until they were satisfied that they fully understood the activity. Susan described their approach to an activity in which a washer, obscured by the edge of a bowl, is made visible again if water is poured into the bowl:

> It threw me, I couldn't work it out. I honestly thought I was seeing things at first. We did it a couple of times and I thought it must have moved, so one time I put my finger on the washer to make sure it didn't move and the second time I found some blue tack or something on the bench and I stuck the washer down to make sure it didn't move this time but I thought it actually moved... [My partner] and I were really trying to work it out thinking it moved. We thought the water must have made it move. [interview]

Susan [and her partner] were not prepared to leave this activity until they were convinced that it was the water making the difference. Persistence and reinforcement were necessary conditions for understanding the concepts in the activity.

DISCUSSION

This study finds that both the quantity and quality of science experiences in the past are closely related to present confidence to learn science. Negative episodes in secondary school and the experience of science as masculine were important contributors to current negative attitudes. For the teachers who lacked confidence in their ability to learn science, the strangeness and perceived difficulty and masculinity of this subject were major problems. These teachers appear to have been alienated by the secondary science experience which emphasised subject maintenance and preparation for tertiary courses. They could not recall experience of primary science which may have been more 'user friendly'. In Paul's case, there is evidence that familiarity with science is an important source of confidence, just as important as accurate ideas and academic success.

The study affirms the importance of the learning environment in changing preservice teachers' negative attitudes to science. This involves creating an atmosphere that allows questions to be asked and answered by all learners. Participants should be valued and their contributions treated with respect. It is important to move away from a "right wrong" mentality, to seeing participants' questions and answers as starting points for the learner in concept development. This allows the lecturer to "get into the learner's concept map" and thus assist the learning process. A slow pace of presentation allows for a thorough exploration of ideas and activities enabling learners to go beyond concrete experience to build abstract concepts. This approach avoids the discouragement experienced by preservice teachers who are presented with too many new ideas at one time.

Many of the participants described themselves as visual and hands-on learners. They had difficulty with abstract ideas. Demonstrations in lectures which added a visual dimension to concepts were popular. The activity based workshops were also greatly appreciated. This supports the suggestion made by Tobin and Garnett (1984) that preservice teachers who had difficulty with formal reasoning would benefit from concrete activities in workshop style contexts. Science concepts are, however, abstract and require formal reasoning. Although the preservice teachers felt safe in concrete learning situations, they gradually came to realise the value of thinking, reading and writing in concept development.

A constructivist approach to learning could well provide the key to effective science education courses for preservice teachers. Such an approach allows for learner dignity and the slow and deep development of concepts. The social aspects of knowledge construction are also provided for in this approach and group work becomes important. However, there can be some negative consequences of this approach. Participants need good cooperative learning skills for a constructivist approach to be effective. If these skills are not well developed, some group members may dominate discussion and have their ideas accepted as appropriate without proper debate. Gender can be a contributing factor here as female students are sometimes reluctant to share their ideas in group situations. This finding reinforces the importance of early primary school experience of science as a socially constructed body of knowledge, where cooperative learning is often an important feature.

The biography of the five teachers lends support to the assertions made by Malcolm (1989), that many of those who choose primary teaching have little background in physical sciences or technology, and that the attitudes that turned them away from science as students operate for them still as teachers. This study confirms the findings of other researchers that lack of confidence with science can be attributed, in part, to gender. Confidence and background go hand in hand. Lack of background meant that teachers were reluctant to assert themselves in group learning situations and hesitant in handling equipment. Lack of confidence in approaching new concepts in turn leads to an impoverished science knowledge.

While we agree with Malcolm (1989) that there is a need to teach more science in schools, we suggest that the way science is taught is of the utmost importance. Here, preservice education can play an important role. While acknowledging the difficulty of changing the beliefs of primary teachers at the inservice (Wallace & Louden, 1992) and the preservice level (Kagan, 1992), this study has shown that, by using a supportive learning environment, concrete experiences and a gradual introduction of new ideas and terminology, progress is possible. Modelling the use of constructivist teaching methods at preservice level offers some hope for the introduction of such methods in primary schools. It may be slow and uncertain but it offers one positive and realistic path to improving primary science.

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FACTORS PERCEIVED TO HAVE ENABLED 25 WOMEN TO DEVELOP EXPERTISE TO TEACH PRIMARY SCIENCE

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ABSTRACT

This paper outlines the findings of a study which involved expert/committed female primary science teachers and examined their perceptions of the main factors that led to the development of their expertise. The study focuses on the women's formal education, early influences outside formal education and their recent training and development. The last of these is the main one identified in research literature as having influenced people to develop an interest in teaching primary science.

INTRODUCTION

In the past science has had a low priority in the primary school curriculum but with the introduction of the nationally developed Statements and Profiles, which identify science as a required area of study for all levels of schooling, its status has changed. Science can no longer be regarded as an optional area of the curriculum in primary schools.

It has been recognised that women are under represented in science and over represented in primary education. The Primary Education Review (Education Department of SA, 1988) suggested that female primary teachers, do not teach science because they do not have the interest, knowledge or confidence. As the majority of primary school teachers are women it has become more urgent that they feel confident to teach science and will be able to competently implement the Statement and Profile in Science. However, there are women who are leaders in primary science in South Australia and it is this group that the research focuses on. Why has this group of women developed an interest and expertise in the teaching of science?

By examining the background and experiences of these women who have developed the confidence and competence to teach science, the research identified factors that have contributed most significantly to their expertise in primary science education. This paper highlights the findings from the study and provides insights into what women perceive have developed their interest in science education. Should providers of both preservice and inservice science education take these findings into account when planning programs then hopefully more women would have access to positive science experiences in education and as result be more confident to teach science to primary students.

RESEARCH LITERATURE

Eighty five percent of South Australian primary teachers are women and many consider they lack skill and confidence in teaching science (Education Department SA, 1988; Yates & Goodrum, 1990). If children in primary schools are to be taught science and to develop a positive attitude to it, it is crucial that women teachers, become more confident and competent in science (Bearlin, 1990; Whyte, 1985; Kelly, 1987). Research seeking to identify factors that women perceive to have contributed to their science expertise has yielded information on preferred methods of training and development (Bell, 1993; Kirkwood, Hardy & Bearlin, 1990; Goodrum, Cousins & Kinnear, 1992; Rennie, Parker & Hutchinson, 1985). However, this *research has not been linked with the early background and formal education experiences of* primary science teachers.

Although science has gradually gained status and importance in the last decade science is still considered a low priority area in the curriculum in many schools. Training and development programs incorporating a constructivist theoretical underpinning have shown to be the most successful in increasing the confidence and competence of female primary teachers to teach science (Bell, Kirkwood & Pearson, 1990a ; Crawford & Zeegers, 1993). Some recent inservice and preservice programs have been geared to addressing the prior negative experiences of women teachers in science (Goodrum, Cousins & Kinnear, 1992). By valuing their knowledge and skills and negotiating a program on a needs basis they are seen to achieve greater relevance (Crawford & Zeegers, 1993; Bearlin, 1990; Bell, 1993)). All aspects of the program including mode of teaching, the selection of content, and the creation of context, must be gender sensitive.

Society has created the male image of science and schools support this by reproducing and reinforcing stereotypes (Kelly, 1987; Whyte, 1985; Kahle, 1988). The literature suggests that though science teaching is currently undergoing radical rethinking and practice there is still a real inequity when participation rates in science are compared for males and females at all levels of education. This trend has continued despite ten years of research and funding directed at improving women's participation in science (Kelly, 1987). It is also clear from a wide range of research and field evidence that unless teachers reconstruct the content and structure of many scientific and technological disciplines, many girls and some boys will not participate (Handley & Morse, 1984; Rosser, 1992; Kahle, 1988; Keller, 1982; Kelly, 1987). In accord with the view presented in the literature that most women have endured negative experiences and have had limited access to science (Kelly, 1987; Harding, 1983) this research focuses on a group of women who have been successful despite any difficulties they may have faced in their education and early background.

PROCEDURE

Identification of participants

Twenty five women who were highly committed to teaching primary science, held leadership positions in schools and were actively involved in promoting science were involved. The following criteria were used to select the participants.

(1) The participants saw themselves as successful and confident science teachers in the primary classroom and have been involved in such activities as:

- curriculum development in science
- being a committee member of Primary Science Teachers Association
- being recognised for their innovative classroom science program by organising extra curricula science activities eg Oliphant Science Awards, Science Week Activities
- organising Training and Development Programs within their school.

(2) They have won leadership positions in schools as a result of their expertise in science. Positions include key teacher, coordinator, focus teacher, Advanced Skill Teacher 1.

Volunteers were contacted and invited to participate via one of the following channels

- Committee of Primary Science Teachers Association.
- TASC (Technology and Science for Children Focus School Program).
- SCI TEC (the former focus school program).
- Advanced Skill Teachers 1.
- Key teachers in science.

Collection of data

Journal. An introductory telephone call informed them of the nature of the research and what was expected of their participation. In order to stimulate and focus information for the questionnaire and follow-up interviews, the teachers were asked to reflect on such issues as their background in science and recent training and development experiences that they believe have contributed to their expertise, in a similar approach to that used by Bell et al., (1990b). It was suggested to the teachers that they jot down their ideas in a journal and then use this as a reference for completing the questionnaire. As it was stressed that the journal was their personal writing, it was difficult to determine how many of the teachers found the journal to be a useful tool. However the following comments made later provided me with some insight:

> I'm sorry my questionnaire is late but I misplaced my journal [PSTA committee member].
> You know what a reluctant writer I am. Well it took ages to get around to putting pen to paper but one night I was in the mood and I just sat in the lounge and out it poured. I've included my journal, it may be of use to you [SCI-TEC focus teacher].

Questionnaire. A time frame of four weeks was allocated for the introductory phone call , beginning the journal and the distribution of the questionnaire. The questions focused on the three aspects of these teachers' experiences which research literature identified as having contributed to teacher expertise viz formal education, early influences outside formal education and training and development. The complex data that was collected was analyzed for patterns to illuminate key factors in teachers' development as science educators. Identifying key phrases, counting frequencies of themes and categorising data under headings assisted analysis. The information was collated into fields and entered into a data base. This enabled cross referencing particularly in the structured questions eg How many junior primary teachers who were part time had completed their Bachelor of Education?

Interview. The purpose of the interview was to clarify and amplify information gathered in the questionnaire. Twenty teachers indicated that they were available for interview, but time constraints unfortunately restricted the number interviewed to six. Selecting at least one participant from each of the four groups (Primary Science Teachers Association Committee; SCI-TEC; TASC; Advanced Skill Teacher 1 plus 2 key teachers in science chosen at random out of the remainder) ensured that a range of views was represented. The 50 minute interviews were transcribed, responses collated and as subheadings emerged the information was reorganised. A copy of the findings and results was forwarded to participants to check for accuracy.

FINDINGS AND RESULTS

The responses from the interview enriched the data provided in the questionnaire, and confirmed the findings as the teachers had an opportunity to expand points that they had briefly touched on in their questionnaire. The findings listed below are a combination of the questionnaire and interview data.

Formal education

The fact that more than half of the teachers had no or very little recollection of primary science experiences confirms the low profile of science in the primary school curriculum during the late fifties and early sixties when all of these teachers attended primary school. Recollections of any primary science, was overwhelmingly "nature science".

Few of these teachers have a physical science background The majority of these teachers studied biology and general science at secondary school. Sixteen completed year twelve biology whilst three completed chemistry and two physics. There were seven teachers who did not study any science at year twelve.

The women described their secondary science experiences with vigour and in detail. Twenty three teachers made some comment about how the subject was taught, including fourteen who mentioned how teacher -directed the lessons were. It is clear that their participation in science was passive, with lessons being remembered for lots of chalk and talk, watching teachers doing demonstrations and copying notes from the board. Though in most cases this information appeared a negative recollection, there were 6 who remembered similar experiences in a positive light. They enjoyed recording information, took pride in their bookwork and felt very mature and important doing experiments in the laboratory.

In both physics and chemistry the recollections indicated that the subjects were hard, and contained examples of male scientists and the concepts illustrated were of greater interest to boys eg rockets, bikes and cars (Ives,1984). Biology was seen to be relevant, easy to understand and more female oriented. General science (Years 8-10) at secondary school was seen to involve little understanding, just a great deal of rote learning. The teachers' feelings and attitudes to secondary science were mainly negative, as they recalled being too embarrassed to ask questions, disenchanted that they had to have the right answers, feeling that they always seemed to miss the vital clue and seeing little relationship between science to everyday life.

Twenty one of the teachers involved in the research studied science/science education at college/university, with sixteen of these doing it as some form of general study. The majority of the women who took science as a general study took biology, general science, geology and/or nature science. Many teachers who had majored in science at tertiary level did not teach it early in their careers. A science background does not seem sufficient to ensure science is taught regularly in a primary classroom unless it is accompanied by relevant methodology courses at undergraduate level and later an opportunity for participation in long term training and development programs for practising teachers.

Early influences outside formal education

The sixteen people who saw their "active" early childhood as a catalyst for their interest in science, mentioned such things as enjoying climbing trees, playing with train sets and pulling things apart. They saw this as a way of helping them relate to the world around them and developing an interest in how things work. This conceptual framework was challenged and built on when experiencing science related activities both at school and home. Several comments referred to how their behaviour was "tomboyish", not at all passive and that they were not interested in dolls and dressing up. Overfield (1981) goes further by suggesting that "Woman ... is only able to enter and pursue a scientific career by virtue of denying everything that the scientific ethos says is women's nature, or by becoming a surrogate man". Being naturally curious, asking questions and having an inquiring mind were all recognised as being important factors. Ten teachers connected their interest and experience with the environment with the development of an interest in science in later years.

Twenty one participants believed that male members of their family had been positive role models and were responsible to some degree for them developing an interest in science. Examples of why they saw these as the greatest influence included "spending weekends tinkering with dad in the shed" and "my brother helped me with my chemistry homework". Twelve mentioned their female family members as being a key influence.

Although there was a whole section in the questionnaire allocated to early childhood background/education, and the directions for the journal asked questions about this period in their lives, only one person included it as a factor perceived to have contributed to her expertise to teach primary science, whereas thirteen people included training and development experiences that focused on whole school change.

Significant science training and development

The teachers had all been involved in a variety of recent training and development activities ranging from "one-off" workshops organised by the Primary Science Teachers Association to long term training and development programs initiated and coordinated through the Education Department of South Australia. Box 1 summarises their most significant sources of training and development. All these programs were continuing programs which aimed at long-term, whole-school change, and not merely the training of individuals. They spanned periods up to several years and gave the participants an opportunity to reflect upon their practice. All programs mentioned involved some form of "train-the-trainer" method of in-service which also took into account the skills and expertise teachers brought to the program. The teachers recorded that the inservice personnel with whom they had worked were noted for their inspiration, collaborative skills and practical approaches.

BOX 1

Most Significant Training and Development	**Teachers (N=25)**
Science and Technology Focus School Program (SCI-TEC) 1988-1991	6
Workshops at school	6
Technology and Science for Children Focus School Program (TASC) 1992-94	4
Coordinators/Focus Teachers team teaching/working in my class	3

SUMMARY OF FINDINGS

Nearly all participants mentioned as a contributing factor the support or influence of key people. A wide variety of people were mentioned in this category including focus teachers, coordinators, peers, teaching mates committed to science, lecturers at college/university and family. These key people provided challenging experiences and programs as well as developing support networks where teachers could share ideas and classroom strategies. The opportunity for reflection and professional exchange of information in supportive groups also had a large impact on many of these teachers. Training and development programs that have contributed most to these teachers expertise have been those that have been long term and focus on whole school change.

The excitement and curiosity of children, as well as their own discovering and learning about phenomena in the world were perceived as important in the development of their science expertise. Many teachers stated that their expertise in science evolved from their love of nature and appreciation of the outdoors. This environmental interest and expertise provided teachers with the confidence to incorporate other areas of science in their program.

Few teachers had any recollection of their primary school science, and although they had clear recollections of their secondary science, these were generally negative especially with regard to physical science. The majority had completed biology to year 12 level but very few had completed physics and/or chemistry to an equivalent level. At tertiary level most had completed a general study in science, biological sciences being the most dominant. Very few considered their background in science or educational experience had contributed to their expertise/commitment to teach science to primary students. They believed that recent training and development was much more significant.

Training and development had provided opportunities for teachers to explore different methodologies and then return to the classroom to trial them. The support of coordinators and focus teachers encouraged teachers to take risks and implement changes in their classroom practice, all of which highlight the importance these teachers place on practical training and development. A non-deficit approach ensured that teachers' skills and knowledge were valued.

Supportive environments were seen as most important in the teacher development process. Teachers commented most often on the need for personal support during the time they were changing their views and beliefs about teaching and learning. It was the support of the group members and not just that of the facilitator that was helpful to the teachers.

CONCLUSIONS

This research clearly indicated that there were many inter-related factors that contributed to the women's expertise in teaching primary science, however five factors stood out:

- influence and support from key people such as teachers, family, focus teachers, coordinators and university lecturers
- their own natural curiosity, personal interest, inquiring mind, and enjoyment of challenges and problem solving
- participation in long term, whole school training and development programs
- interest in and experience with the environment.
- the joy of children discovering and learning in science

To develop the confidence and competence to teach primary science, this research highlights that women need access to long term training and development programs based on a constructivist theory of learning and support networks in science.

Information from the questionnaire and interviews indicated that although the respondents valued their early experiences, they believed that recent training and development had made the greatest contribution to their expertise/commitment.

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THE EFFECT OF THE DIRECTION OF MOTION ON STUDENTS' CONCEPTIONS OF FORCES

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ABSTRACT

The ability to generalise principles to a range of situations is generally considered to be important in science education. However, several studies have found that students do not consistently apply their conceptions in the study of mechanics, and that they respond to irrelevant contextual features of the question, such as the type of object in motion. The present study was designed to investigate whether the direction of the motion (i.e. vertical or horizontal) was a contextual feature which influenced students' ideas about the forces involved in motion. The results indicated that 14% of the university science teaching students studied and 25% of the Year 10 students were influenced by the direction of the motion. Some of these students described a 'motion force' in one direction (usually vertical) but not the other, while others described forces opposing the motion in one direction (which was always vertical) but not the other.

INTRODUCTION

Over the last two decades a great amount of educational research has focussed on the ideas which students have in relation to scientific concepts (e.g. Driver, 1989). It is now well established that during their experiences in everyday life children develop their own naive ideas which they use to explain the natural phenomena they observe in the world around them. In this paper, the term 'alternative conceptions' will be used to describe these ideas.

The alternative conception which has probably received the most intensive study is the notion that the continuous action of a force is necessary to keep an object in motion. Although it represents a way of thinking which has been rejected by the scientific community since the eighteenth century it has now been established that this idea predominates amongst both secondary students (Osborne, 1981; Gunstone, 1990) and tertiary students (Clement, 1982).

The ability to generalise principles to a range of situations is generally considered to be important in science education: even elementary science programs are commonly aimed at helping children to understand and interpret their environment using such principles. Thus it is important to understand the factors which affect the ability of students to generalise their conceptions even though these conceptions may be at odds with accepted scientific viewpoints. There is some evidence which suggests that, in spite of the predominance of the 'motion implies a force' conception, many students do not use it consistently (Halloun & Hestenes, 1985; Finegold & Gorsky, 1991).

Some researchers have studied the reasons for this lack of consistency. Reif (1987) concluded that "novice students' knowledge about a scientific concept is highly fragmented and does not specify how to interpret a concept in specific instances". In order to solve a problem involving physical phenomena physics students would "rely on various special knowledge elements stored in memory, try to retrieve one of these, and apply it without much subsequent reasoning" rather than invoking general laws or concepts. Other studies have noted the effect of context on students' responses. For example, Chi, Feltovich and Glaser (1981) found that novices were influenced by the types of physical objects, such as 'rotational things' or 'blocks on inclined planes' when attempting to classify problems in mechanics. Further support for this has been provided by Fischbein, Stavy and Ma-Naim (1989) who found that amongst tenth and eleventh grade students the action of impetus depended on the features of the moving body and in particular its shape, weight and function. Similarly, Whitelock (1991) tested students aged 7 to 16 years and found that "the animate nature of moving objects...was an important distinction in subjects' consideration of causes of motion".

It is possible that the nature of the physical objects involved is not the only contextual factor which impinges on students' conceptions of forces and motion. In a preliminary study on consistency of responses, 15 and 16 year-old high school students were presented with a range of questions concerning linear motion (Palmer, 1993). The results suggested that the direction of the motion (i.e. vertical versus horizontal) may have been a contextual factor which influenced the responses of some students.

The purpose of the present study is to investigate the effect of the direction of the motion on students' conceptions of the forces involved in linear motion.

METHOD

The instrument

This study used a survey approach supplemented by individual diagnostic interviews. The relevant questions used in the survey are presented in Box 1. Question 1 concerned a ball moving vertically upwards, while Q5 concerned a ball moving horizontally. Answers to these questions, along with the written explanations in Q2 and Q6 were compared in order to assess whether the direction of the motion was a contextual factor which influenced students' responses. Q7 and Q8 concerned balls moving vertically downwards and were included to clarify the nature of some of the responses (as explained in the results). The questions were validated (for readability and ambiguity) by two physics lecturers at the University of Newcastle. The survey also contained some other questions on mechanics which were not relevant to this research question.

BOX 1

Selected questions, without their accompanying diagrams:

1. Imagine that you have just thrown a tennis ball as hard as you can, straight upwards into the air. Draw and name the force or forces, if any, acting on the ball as it is still moving upwards quite quickly, well after it has left your hand.
2. Explain why the ball (in Q1) slowed down as it got higher.
5. Imagine that you have just rolled a tennis ball straight along the carpet (which is flat and level). Draw and name the force or forces, if any, on the ball as it is still moving along, well after it has left your hand.
6. Explain why the ball (in Q3) slows down and then stops.
7. Imagine that you are standing on a table and you have just thrown a tennis ball as hard as you can straight downwards to the floor. Draw and name the force or forces, if any, on the ball as it is still moving straight downwards, well after it has left your hand.
8. Imagine that you are standing on a table and you have just let a tennis ball drop by itself to the floor. Draw and name the force or forces, if any, on the ball as it is still moving straight downwards, well after it has left your hand.

The sample

The survey was administered to two groups of students. The first group consisted of 275 Year 10 students who came from eleven schools which covered a range of socioeconomic conditions in the Newcastle area. One whole science class participated from each school. The classes represented a range of achievement levels (i.e. classes streamed as upper ability, middle ability and lower ability, as well as unstreamed classes). Care was taken to mix the class types and the socioeconomic areas. For example, upper ability classes came from both upper and lower socioeconomic areas.

The second group consisted of 69 pre-service science teachers from the University of Newcastle. There were four subgroups of these students - one subgroup from each of the four years of teacher training. All of these students had studied mechanics at university, although some more recently than others (mechanics is taught in first year only).

Students were asked to complete the survey during their normal science classes. After each group completed the survey, a small number of volunteers (representing just over 10% of the sample overall) participated in individual, audiotaped interviews. The interviewees were asked to describe and explain their responses to the survey questions and to describe (if they could remember) what their ideas had been before instruction in mechanics.

RESULTS

Categorisation of responses

Generally, if the student, when responding to Q1 or Q5, drew an arrow in the direction of the motion of the ball then they were assumed to be indicating a 'motion force' for that particular question. (The interviews indicated that this was almost invariably the case). An important exception to this was if the student drew an arrow in the direction of the motion of the ball and labelled it with a term such as velocity, acceleration, kinetic energy, inertia or momentum which may have represented either a misreading of the question or a use of the term to name a 'motion force'. In order to solve this dilemma, Q7 and Q8 were referred to. The former concerned a ball which had been thrown vertically downwards and in the latter the ball had simply been dropped. Those people who used a term such as velocity, acceleration, kinetic energy, inertia or momentum in Q7 but not Q8 were assumed to have the alternative conception of a 'motion force'. The interview data confirmed that this was a valid assumption. The responses of those students who used the term in both questions or whose responses were uninterpretable were considered to be inconclusive.

This system of coding was tested using a two step process of agreement which was carried out between the author and a lecturer in physics at the University. In the first step, a representative sample of 10 completed surveys was independently examined and agreement using this system of categorisation was found in 8 of the 10 cases. After discussion and resolution of the discrepancies another representative sample of 10 completed surveys was examined and agreement was found in every case.

The responses of each student were categorised according to the above criteria in order to determine the main types of forces which the students described. The results are presented in Table 1.

TABLE 1
FREQUENCY OF THE MAIN TYPES OF FORCES IDENTIFIED BY STUDENTS

	Type of force			
Group	'motion'	gravity	air resistance	friction
University*	64%	100%	35%	90%
Year 10 **	72%	95%	17%	44%

* n=69; ** n=275

In each group a majority of the students gave answers which were indicative of a force in the direction of the motion. No gender differences were apparent. Typical written responses included "the force exerted by the person is becoming less as gravity is taking over..." and "the force diminished that kept the ball moving". Some students appeared to hold alternative conceptions about the nature of gravity, friction and air resistance but for the purposes of this study they were considered to be orthodox as long as the direction of the force was correct.

Differences between interpretations of vertical and horizontal motion

The responses of 80 students showed differences between vertical and horizontal motion. This represented 14% of the university students and 25% of the Year 10 students. The responses fell into two distinct groups. The first (and smaller) group consisted of those who indicated a 'motion force' in one direction but not the other, while the second (larger) group consisted of those who indicated a force opposing the motion in one direction but not the other (note: these groups are not mutually exclusive - one student was in both groups). The groups are described below.

Group 1: 'Motion force' in one direction but not the other. A total of 20 students (representing 6% of the university students and 6% of the Year 10 students) indicated a 'motion force' in the vertical direction but not the horizontal (see Table 2).

TABLE 2

NUMBER OF STUDENTS WHO INDICATED A 'MOTION FORCE' IN ONE DIRECTION ONLY

	Type of force	
	vertical only	horizontal only
University	4	2
Year 10	16	4

In response to Q5 the majority referred only to frictional force slowing the ball. For example, one student drew an arrow in the direction of the motion in Q1 and labelled it 'thrusting', had no 'motion force' arrow in Q5, then stated in Q6 that "There is nothing pushing it. therefore the friction between the ball and the floor will cause the ball to stop" [grammar not corrected]. One interviewee provided an explanation which implied that in the horizontal direction the ball was just rolling and didn't need a force to push it along. When asked about Q1 this student had previously stated:

> Forces up and down, the way I look at it when an object has been thrown up. So you would have an acceleration upwards. That's what I have put by the up arrow. Um, then there would be negative forces acting down, against the acceleration, they would be air resistance and gravity.

Further questioning confirmed that this student equated acceleration with a motion force. Then describing the situation in Q5 he stated:

S: There'd be no initial acceleration like there was for the other questions. You've already rolled it and you're watching it now. So you've already applied a force to get it moving.

DP: So that's a different situation to where you'd thrown [vertically] as far as that the force pushing it along is not there?

S: Right. That's right.

The other six students (representing both university and Year 10) described a 'motion force' in the horizontal direction but not the vertical. One student wrote in Q2 that 'The combination of all the forces involved; gravity, wind resistance, friction slowed that ball over a distance as the *push force* was an impulse force at the bottom' [italics inserted], and then in response to Q6 wrote that the ball slowed down "Because the sum of the forces [backward direction indicated] is greater than the sum of the force [forward direction indicated]". Terms such as 'push force' were often used by other students to describe the 'motion force' so one interpretation of this student's choice of the term 'push force' could be that he had previously held the alternative conception and had corrected it in the situation of vertical motion but not horizontal.

Group 2: Retarding force (gravity/friction) in one direction but not the other. A total of 55 students (representing 6% of the university students and 19% of the Year 10 students) were identified. All indicated a retarding force (i.e. a force which opposed the motion of the ball) in the vertical direction but not the horizontal. Their responses indicated that when the ball was moving vertically gravity and/or air resistance slowed it down, but in the horizontal direction a retarding force was not needed to slow the ball down. The majority of the people in this group (43 out of the 55) indicated that the ball moving horizontally would slow down when the 'motion force' ran out. For example, in response to Q2 one student wrote "The ball slowed down as its momentum decreased and gravity started to act on the ball". Analysis of the other responses indicated that this student used the term 'momentum' to refer to a 'motion force' and then wrote in Q6 "The ball has no momentum left and as it hasn't got any forces acting on it, it stops rolling". Other responses such as "lack of energy", "it runs out of force pushing it" and "it has no more force to push it any further" were common. A minority of the students (4 in total) gave no indication of a 'motion force', but appeared to believe that the moving ball would slow down spontaneously. For example, in response to Q6 a student wrote "It slows down because the force that was applied to it, to get it rolling is no longer there, so it automatically slows down". The remaining eight students gave responses which were inconclusive for the presence of a 'motion force' but did include a retarding force in the vertical direction only.

The interviews indicated that some students were quite sure that there was no force acting against the ball whereas other students appeared to be less sure, and their responses may have been due to a lack of knowledge about friction.

Effect of gender, level of study and school

For the purpose of statistical comparison, all the students who showed differences between vertical and horizontal were grouped together. Amongst the university students this group included 3% of the males and 38% of the females. A chi-square test showed that this difference was significant ($X^2=8.07$, $p<.0045$, $N=68$; note that numbers may vary slightly as not all students indicated their gender). Thus a larger proportion of female than male university students appeared to be influenced by the direction of the motion. However, this difference was not apparent amongst the Year 10 students; 32% of males and 38% of females were identified and this difference was not significant ($X^2=.41$, $p<.52$, $N=274$). One possible reason for this discrepancy may be that amongst the university students more of the males than females had studied physics in Years 11 and 12 (the proportions are 66% and 28% respectively) and thus had had a greater exposure to mechanics.

The Year 10 students from classes streamed as 'top' classes were compared to those from 'non top' classes (i.e. middle classes, lower classes and ungraded classes). Thirty three percent of the former and 35% of the latter were identified as showing differences between vertical and horizontal. This difference was not significant ($X^2=.03$, $p<.87$, $N=275$). Thus, this phenomenon is one which is not restricted to students in lower classes or in higher classes.

The results from each school (there was one class from each) were compared in order to determine whether the identified students came from a particular school. The results are shown in Table 3. This shows that there were identified students in each of the 11 schools. Although the proportions varied from 7% to 43% it is apparent that these students did not come from any one particular school, but appeared to be generally spread through the population.

TABLE 3
PERCENTAGE OF STUDENTS FROM EACH SCHOOL DEMONSTRATING DIRECTIONALITY

	School										
Group	1*	2*	3*	4*	5*	6	7	8	9	10	11
1	0	18	16	4	0	6	10	17	4	5	3
2	25	14	12	30	7	13	10	17	39	15	20
Total	25	32	28	34	7	19	20	33	43	20	23

* denotes a 'top' class; group 1 = motion force directionality; group 2 = retarding force directionality

Conceptual development

Each Year 10 student who was interviewed was asked if their answer to Q1 would have been any different before they learnt about forces at school. The results are shown below.

TABLE 4
YEAR 10 STUDENTS' DESCRIPTIONS OF HOW THEIR CONCEPTIONS OF FORCES IN QUESTION 1 HAD CHANGED SINCE SCHOOLING

Description	Number
no change / can't say	13
upwards force before/ upwards and/or downwards after	17
downwards force before/ upwards and downwards after	1
no forces before/ upwards and downwards after	1

The results indicate that the majority of the interviewees could remember (correctly or incorrectly) having changed their ideas. Of those whose ideas appeared to have changed, the majority started with a 'motion force' and then added the downwards forces as they learnt about forces at school. Although only eight of the interviewees were in groups 1 and 2 (i.e. showed differences between vertical and horizontal) they appeared to follow the same pattern: the majority apparently changing from an upwards only force to upwards and downwards forces.

DISCUSSION

The results from the present study suggest that, for some students (albeit a minority), directionality is a contextual factor which contributes to their lack of consistency in problems concerning motion. Some students conceived of a motion force in one direction but not the other. The fact that in the majority of these cases the direction of the motion force was vertical rather than horizontal may have been because students were aware of the effects of gravity, and considered that the ball would need some force pushing it up in order to overcome this strong downward pull. In the horizontal direction the effect of gravity was not so evident so there was less need for a 'motion force'. Clement (1982) reported similar findings. He investigated the conceptions of university students with regard to motion and found that in the case of periodic motion 'more invented forces were shown on the upswing of the pendulum than on the downswing'. He also noted that in the case of the tossed coin the error [i.e. use of alternative conception] rates were higher than for the pendulum problem 'because the opposition between the direction of the motion and the gravitational force is more pronounced in the coin problem'.

However, the majority of the students who demonstrated directionality were those who had a 'motion force' in both the vertical and horizontal directions but a retarding force in only the vertical direction. The majority of those who were interviewed from this group indicated that their initial belief (i.e. before science instruction) was of a 'motion force' only. An explanation could be that their initial belief was that a 'motion force' kept a ball moving in any situation (whether vertical or horizontal) but that this 'motion force' always gets used up, so the ball slows down. Then in early science lessons they would have learnt about the force of gravity and this would have enabled them to explain the resulting change in direction of the ball travelling vertically, but gravity did not appear to affect the ball travelling horizontally, and because the ball did not change direction, their initial belief was still satisfactory. Thus, they have incorporated the concept of gravity into their understanding, but not the concept of friction with the ground. This implies that their learning in mechanics is proceeding by a series of small steps in which certain forces but not others are incorporated into their understanding at any one time. Nussbaum (1989) proposed that learning in science "forms an evolutionary pattern in which the student maintains substantial elements of the old conception while gradually incorporating individual elements from the new one". The results from the present study suggest that for some students, the development of mechanics concepts occurs in just such a way.

Implications for conceptual change theory

The issue of 'evolutionary' versus 'revolutionary' change has been discussed by Driver (1989). It has been argued that the movement from a pre-Newtonian view to a Newtonian view of mechanics requires a revolutionary change of conceptions (Champagne, Klopfer & Anderson, 1980). However, it is apparent from this study and others mentioned above that some students do not have a theory-like conception of motion, but rather a relatively loose collection of ideas which are influenced by factors such as the direction of the motion and the type of object in motion. As their conception is not 'theory-like' it follows that changing their conception does not necessarily require a revolutionary change in thinking. For these particular students it is possible that the process of conceptual change could come about by a series of relatively small changes in thinking about particular instances. Each change would apply to a specific context (e.g. motion in a vertical direction) in which the idea of a motion force is discarded (e.g. this study identified one student who appeared to have rejected the idea of a motion force in the vertical direction but not the horizontal). In this way, the final loss of a motion force conception may simply be attained through a process of evolution rather than revolution.

Implications for physics teaching

The results of this study can be interpreted as emphasising the need for a wider range of critical examples in physics lessons. In many cases teachers tend to introduce topics in mechanics in a very superficial way, and then concentrate on the application of formulae. It is difficult to see how students can be expected either to develop the ability to generalise their ideas or to change their conceptions without exposure to a wide variety of qualitative problems.

It also appears that a greater variety of problems is needed for assessment purposes. As such a large proportion of students was found to have the alternative conception it is surprising that teachers have not identified it. If more types of problems relevant to each concept were included in science tests then teachers may have more success in assessing the nature of students' difficulties.

Finally, the results argue that many students are not assimilating scientific concepts as effectively as teachers might wish. For example, in Year 10 the majority of the students had no conception of the force of friction retarding the motion of the ball rolling horizontally. As many of these students will not formally study any more physics during their lifetime (since it is not compulsory during their remaining two years at school) they will have little opportunity to further their understanding. It is important for science courses to incorporate means for promoting gradual change in pupils' understanding (Nussbaum, 1989).

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MEASURING AFFECTIVE OUTCOMES FROM A VISIT TO A SCIENCE EDUCATION CENTRE

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ABSTRACT

One of the problems in measuring affective outcomes from visits to science education centres like the CSIROSEC laboratories, is that different students have quite different experiences. They attend to different sets of activities or exhibits for different lengths of time, they have different amounts of previous knowledge and they may interact in different ways. Measurement of affective outcomes must take account of this diversity and, if it is to be useful for teachers, a measuring instrument must be brief, easy to understand and to score. This paper reports the results of a pilot study which devised a way of measuring affective outcomes from visits to a CSIROSEC. Specifically, students responded in terms of how easy they found various aspects of the activities, their enjoyment of what they did, and how helpful they found the visit in terms of their wider views and understanding about science and scientists.

INTRODUCTION

The Commonwealth Scientific and Industrial Research Organisation Science Education Centres (CSIROSECs) are science laboratories equipped to provide "hands on" learning experiences for school children in all branches of science. There are CSIROSECs in each state and the Northern Territory. The one in Perth opened at the Scitech Discovery Centre in 1989. Teachers book in their classes and, together with the CSIROSEC Manager, select a range of experiments and activities appropriate for the purpose of the visit. After a short introduction, students usually work in small groups and rotate through three to five activities, as many as can fit into the time available.

The CSIROSECs plan to implement the aims of the CSIRO Education Programs, which are to:

- alert school students, their families and teachers of science to CSIRO's contribution of scientific research to our community;
- encourage students to participate in scientific activities especially those related to the applications of science; and
- encourage students to take up careers in science.

Centres such as these offer significant opportunities for out-of-school learning in science. In a recent pilot study at the Perth CSIROSEC, Rennie and Elliott (1991) found that teachers brought their classes to CSIROSEC to use the science activities and equipment, as a supplement to the school curriculum, as an enrichment experience for the class, or to participate in special theme activities often related to concurrent exhibitions at Scitech. Gottfried (1980) found that teachers visited the Biolab at the Lawrence Hall of Science for similar reasons. Clearly teachers perceive value in visits to laboratories such as these, but is the value really there? What are the outcomes of visits to CSIROSEC? The pilot study referred to earlier attempted to devise ways to measure both cognitive and affective learning from a CSIROSEC visit and this paper reports the part of the research which considered affect. The measurement of cognitive outcomes is reported elsewhere (Rennie, 1993).

The pilot study found that students enjoyed their visit to CSIROSEC: observation of and interviews with students at the centre, and with their teachers then and later, confirmed this. But how can such affective experiences be measured? What kinds of affect are important in determining whether a visit is worthwhile? Are the CSIROSEC aims an appropriate target for measuring affective outcomes?

The problems in measuring outcomes from CSIROSEC are similar to those experienced by researchers in places like museums and interactive science centres, where visitor learning is the object of the research. There is now a large literature base devoted to learning in museums and similar centres. A range of research designs have been used in attempts to measure cognitive and affective outcomes, including experimental (Stronck, 1983), non-experimental (Erätuuli & Sneider, 1990) and ethnographic (Wolins, Jensen & Ulzheimer, 1992). As in other educational fields, some researchers have suggested that a combination of methods may be most effective (Koran & Ellis, 1991). Various methods of collecting data have been tried, including audiotapes and observations (Lucas, McManus & Thomas, 1986), interviews (Tuckey, 1992), videotapes and interviews (Martin, Brown & Russell, 1991), stimulated recall with videotapes (Stevenson & Bryden, 1991), questionnaires (Erätuuli & Sneider, 1990) and subsequent peer-teaching (Gottfried, 1980). These methods have had varied but sufficient success to conclude that some cognitive learning occurs most of the time. There is overwhelming agreement among researchers that students enjoy the visit experience, but perhaps surprisingly, comparatively few attempts have been made to measure specific affective outcomes. For example, in a review of research over 50 years into the effect of field trips/visits, Koran, Koran and Ellis (1989) list 27 studies, less than a third of which included measurement of any kind of attitudes.

One explanation for the limited research on attitudes is that it is not always clear what the attitude object should be. Attempts to measure attitude change have used different approaches. For example, Finson and Enochs (1987) used part of the Scientific Attitude Inventory to measure attitudes towards STS developed during a visit to a science and technology centre focusing on space, and found small positive gains. Rather than use a general measure, Fortner and Lahm (1990) devised an attitude questionnaire about the preservation and use of the estuarine sanctuary which students visited, but they were unable to attribute attitude change to the visit experience. Flexer and Borun (1984) employed a questionnaire which measured enjoyment of the exhibit or lesson (the control treatment) and compared enjoyment of the exhibit or lesson to enjoyment of school classes.

Given that attitudes are learned over time, is it reasonable to expect that students can undergo significant attitude change or development in a short visit or field trip? The limited, and generally uncompelling, research findings for attitude change suggest that it is not. However, there is evidence that students' strongest memories of their visits relate to affective and emotional aspects, although frequently the affective experience is not related to the content of the exhibits (Falk & Dierking, 1992; Wolins et al., 1992). In the light of this, is the affect related to the visit important enough to make the visit worthwhile? For example, is it reasonable to assume that a positive affective experience contributes to cognitive learning?

Increasingly, museum researchers have focused on the importance of affect as a determinant of learning. Koran and Koran (1983, p. 16) state that attitude and curiosity "are closely related and critical to learning in all types of exhibit settings". Boyd (1993, p. 765) claims that "[m]otivation and engagement are the basic elements of effective educational experience in all settings". Roberts (1991) emphasises the importance of affect in terms of motivation to learn, values, state of mind and learning modes. She believes that "far from being marginal, affective factors are fundamental to the processes by which we think and know" (Roberts, 1993, p. 97).

McManus (1993) argues for the artificial distinction between affect and cognition to be forgotten; rather, she suggests, they should be considered as reinforcing each other.

The position taken in this paper is that the value of out-of-school field trips/excursions/visits should be considered in terms of both the affective and cognitive experience. An important corollary is that the visit experience should be considered in terms of students' previous and subsequent knowledge, experience and opportunities to learn.

In a museum or science centre, interaction with exhibits is voluntary. If the experience is not enjoyable, students are unlikely to persist with it. Persistence doesn't necessarily mean that cognitive learning occurs (Hidi, Soren & Weiss, 1994), but it may well be a prerequisite. Further, learning from a museum visit, or from a particular exhibit, is not an isolated experience. Learning depends on what previous knowledge and skills students bring with them to an exhibit and the kind of experiences which follow. Learning during a visit does not have to be about new things. It can occur when previous knowledge is consolidated by linking experiences together in a meaningful way. Similarly, fragments of knowledge gained from the visit experience can be consolidated during later instruction, provided the learner is receptive and able to recall these experiences. If learners consider their experiences during the visit to be rewarding and enjoyable, then it is likely they will be receptive to subsequent related instruction. Hence it is argued that an important role of affect in the visit experience is to prime the learner for subsequent instruction. In other words, an enjoyable and successful visit experience is an important outcome because it can predispose the learner to engage in further cognitive learning. Motivation and willingness to engage in further instruction are most likely to be the important affective outcomes of a visit. In terms of other affective outcomes relating to science, a short visit is more likely to raise students' awareness about science, scientists and future careers than to result in a fundamental change of attitude with respect to these things, although this may also occur.

This argument suggests that maximum cognitive learning associated with the visit requires a positive affective experience together with pre-visit instruction which primes the learner before the visit and post-visit instruction to consolidate the learning experience. Research into pre-visit instruction strongly supports this proposition (Falk & Dierking, 1992; Rennie, McClafferty & Johnston, 1993), but, apart from some confirming work by Flexer and Borun (1984), the effectiveness of post-visit instruction is generally untested in research (Bitgood, 1989).

If affect is perceived in terms of its role to facilitate learning, then what kinds of outcomes from a visit would demonstrate a positive affective experience? Based on previous research into affect which suggested that enjoyment, usefulness and perceived self competence are separate but related components of affect (Rennie, 1986), three outcomes are suggested: first, students' perceptions that they have been successful in what they tried to do; second, they enjoyed what they did do; and third, they thought it was helpful to their learning. This paper reports the results of a pilot study at the Perth CSIROSEC in terms of these three potential affective outcomes.

METHOD

The pilot study began with observation of sessions at CSIROSEC in order to find out what teachers and students do there and to understand the learning context. Data were collected during visits by nine classes from seven schools, using a combination of field notes from observations and interviews with the CSIROSEC manager and assistant, informal conversation with visiting teachers and their students, and formal, follow-up interviews with two teachers. Following this initial phase, an instrument was devised as a means of measuring learning outcomes from the visit. A post-visit questionnaire was the format chosen. It occupied one double-sided page and asked a number of questions about what students did during the visit, their reactions to the visit, and several other questions about the CSIRO to provide information for the manager. Only the section of the questionnaire designed to assess affective outcomes is reported in this paper.

The sample

The sample selected for the pilot administration of the questionnaire was one of convenience, in that advantage was taken of suitable classes who were booked into CSIROSEC. Ten classes from seven different high schools were chosen from the booking list. The class teachers were contacted by telephone and asked if they would spare the time to allow a visitor to their class to administer the questionnaire. Teachers were told its purpose, and all gave permission for data to be collected from their class. The description of the schools and sample given in Table 1 shows that 143 students from Years 9 to 11 were included, covering a range of science subjects. There were 98 boys and 42 girls (3 students did not indicate their sex), and the predominance of boys was attributable to the lower enrolment of girls in the chemistry classes.

TABLE 1
DESCRIPTION OF SAMPLE

School	Year Level	Number of Students	Subject	Weeks Since Visit	Related Instruction
A	9	22	Academic Extension	One	None
B	11	14	Biology	Two	Post-visit discussion
C	11	8	Physics	Five	Second visit, Post-visit discussion
D	11	25	Chemistry	Six	Post-visit discussion
E	11	31	Senior Science	Seven	None
F	10	31	Chemistry	Eight	Post-visit discussion
G	10	12	Chemistry	Ten	Pre-visit discussion

The instrument

The measurement of affect focused on three related variables: the students' perceived success in working with the activities, their enjoyment, and their perceptions of the helpfulness of the visit. Three groups of four items were devised, each with a five-choice response format. The first group was directed at students' perceptions of their success during their working on the activities, and the response choices were 'very easy', 'easy', 'in between', 'hard' and 'very hard'. The second group of items asked about students' enjoyment of these experiences. Response choices ranged from 'not at all enjoyable' to 'very enjoyable'. One item focused specifically on enjoyment working in groups, because this is recognised as an important component of visits to science centres (Blud, 1990; Falk & Dierking, 1992, McManus, 1988). The third group of items asked students' opinion of whether the experiences during the visit had been helpful to them in terms of school work and understanding about science and scientists. The response choices had end points of 'not at all helpful' and 'very helpful'.

Initial drafts of the item wording were discussed with the CSIROSEC Manager, with two other science educators aware of the purpose of the study, and with a group of five high school students to check for clarity of wording and in using the response format. As a result of these checks, the final items were considered to be unambiguous and representative of the variables they were attempting to measure. The wording of the items is given in Table 2.

An additional two questions sought information about the raising of students' awareness about science and scientists. The first asked students whether, before the visit, they had thought that they might like a career in science, and the second asked whether their visit to CSIROSEC had changed their thinking about this. Students were asked to explain an affirmative response.

The timing of the data collection was arranged so that students responded to the questionnaire between one and ten weeks after their visit. This enabled examination of responses in terms of the length of time since the visit. Students were requested not to share their responses with friends and they seemed to experience no problems in understanding or responding to any part of the questionnaire. In each class, the whole questionnaire took between 10 and 15 minutes to complete, but the affective items took no more than five minutes.

RESULTS

The responses to the items were scored 1 through 5, so that the higher score indicated the more positive response. Item means and standard deviations are reported in Table 2, together with the results of a principal components analysis of the 12 items. Three factors accounting for 62.8% of the variance resulted and, except for Item 8, these factors coincided with the three groups of items. Item 8 which referred to enjoyment of the whole visit, tended to split between the Enjoyment and the Helpfulness factors.

The high means and small standard deviations for the Easiness items (Items 1 to 4) indicate that, in general, students agreed that the activities were easy to use and they experienced success in using them. The means of the other items were more variable, with higher standard deviations. The most enjoyed feature of the visit was working in groups, indicating that this social aspect is an important part of the affective experience students have at science centres. Students perceived the visit to be reasonably helpful in advancing their ideas about science in general terms, but not necessarily in terms of school work. However, as Table 1 demonstrates, not all visits were explicitly linked with school work so perhaps this may not be surprising. Results for the final two items suggest that students' awareness of scientists' work and the CSIRO were raised.

Results from two other questions also suggested that the visit had raised awareness about science careers. When asked whether students had considered a career in science before their visit, 50% of students responded 'yes' and 50% responded 'no'. A small group of 15% indicated that the lab had changed their thinking about a science career. Most students explained this in terms of raised awareness about science. For example, a Year 11 chemistry student responded "it made me realise that science and chemistry isn't [sic] really so straight-forward, and that it [sic] can lead to great discoveries". A biology student wrote that "I realised that a science career could be very versatile".

TABLE 2
ITEMS MEANS, STANDARD DEVIATIONS AND FACTOR LOADINGS FROM PRINCIPAL COMPONENTS ANALYSIS

Items	Mean	SD	Factor I Helpfulness	Factor II Enjoyment	Factor III Easiness
In the activities you did, how easy was it for you to					
1. understand the instructions?	3.80	0.86			.78
2. use the equipment?	4.00	0.77			.76
3. get a result for the activity?	3.53	0.96			.79
4. understand what the activity was all about?	3.67	0.96			.53
How much did you enjoy					
5. doing the activities?	3.37	1.14		.73	
6. working in groups?	4.02	1.06		.74	
7. using the equipment?	3.78	1.08		.75	
8. the whole visit to the lab?	3.22	1.22	.48	.66	
How helpful was the visit to the lab in terms of					
9. your school work?	2.66	1.17	.77		
10. understanding about science in your community?	3.10	1.14	.79		
11. getting an idea about what scientists do?	3.76	1.14	.75	.34	
12. getting an idea about what CSIRO does?	3.69	1.25	.69	.32	

Only loadings >.30 are reported.

On the basis of the results for the affective variables, and in order to examine more closely relationships with other variables, three scales were developed. The Easiness scale, comprising Items 1 to 4, had a Cronbach alpha reliability of .74, and the Helpfulness scale, comprising Items 9 to 12, had a reliability of .81. Items 5, 7 and 8 were used to form a scale called Enjoyment, which had a reliability of .83. Item 6 was intuitively distinct from the other three because it referred to a social experience not unique to the visit. Interestingly, although it appeared empirically similar by loading on the Enjoyment factor in the principal components analysis, when included in the Enjoyment scale, it reduced the reliability slightly to .81.

The relationships between the four affective variables, students' school and sex were examined in two-way analyses of variance, and the results appear in Table 3. In no case did the F-value for the interaction effect reach unity, so interaction results are not reported. It can be seen that, except for Group Work, which girls (mean=4.31) preferred more than boys (mean=3.88), there are no sex differences. There are school effects for each variable, however. Comparison of the sums of squares reported in Table 3 indicates that these effects account for between 14% of the variance in the Easiness scale and 9% of the variance in the Helpfulness scale.

Inspection of school means for each variable revealed that there was no systematic relationship in terms of the length of time since the visit, but there was a relationship according to whether there was any pre- or post-visit instruction associated with the visit. Schools A and E which had no related instruction had the lowest means for the Easiness and Group Work scales. School E had the lowest mean for Enjoyment and School A had the third lowest mean. Post hoc contrasts between the means of Schools A and E and the remaining schools indicated statistically significant differences ($p<.01$) for each of these three variables. There was no difference for Helpfulness where, respectively, Schools A and E had the second and fourth lowest means.

TABLE 3
RESULTS OF SEX BY SCHOOL ANOVA ON THE AFFECTIVE SCALES

	Sex		School		
Scale	SS	F	SS	F	Total SS
Easiness	0.08	0.18	7.34	2.90*	60.87
Enjoyment	0.25	0.28	19.82	3.62**	136.77
Helpfulness	0.98	1.16	11.15	2.20*	120.53
Group Work	5.44	5.33*	19.80	3.23**	156.99

* p<.05; **p<.01.

To examine the relationship between the affective variables and cognitive outcomes, correlations with two cognitive variables were examined, the number of activities recalled (which ranged from none to five) and an average score for students' perception of their learning on the activities. Rennie (1993) describes how these variables were measured. Table 4 shows the correlation matrix and reveals small correlations between cognitive and affective variables. The only correlations reaching statistical significance suggest that students recalling fewer activities remembered them as being easier, and enjoyed group work more. Students who learned more from the activities enjoyed the experience more. Correlations between the affective variables are generally moderate and positive, with the largest correlation between Enjoyment and Helpfulness (recall that Item 8 loaded on both these factors) and the smallest between Group Work and perceived Easiness of the activities.

TABLE 4
CORRELATIONS BETWEEN COGNITIVE AND AFFECTIVE VARIABLES

Variable	No. of Activities	Average Score	Easiness	Enjoyment	Helpfulness
Average Score	.04				
Easiness	-.19*	.09			
Enjoyment	.01	.32**	.45**		
Helpful	-.02	.11	.41**	.56**	
Group Work	-.17*	.16	.19*	.45**	.34**

* p<.05; ** p<.01

DISCUSSION

This paper reported the results of a pilot study which posited that the affective outcomes of a visit to a science centre should be defined by students' perceptions of their success in performing the activities, their enjoyment of the experience, and whether they perceived it to be helpful them. Responses to a short questionnaire developed from this position supported the notion of these three dimensions of affect, and three reliable scales resulted.

The results indicate that first, students experienced success on the activities, finding them reasonably easy to perform and achieve a result. Second, students found the visit experience enjoyable, particularly the opportunity to work on the activities in small groups. Third, the experience was perceived to be moderately helpful in increasing their awareness of science in the community, and about what scientists and the CSIRO do. Some students indicated that they had broadened their ideas about science. Fourth, aside from girls' greater enjoyment of group work, there were no differences between the results for boys and girls, indicating that both benefit and enjoy the experience offered by the visit. Fifth, consistent between-school differences in students' perceived easiness of the activities and their enjoyment appear to be more strongly related to whether or not students received instruction associated with the visit than to how long ago the visit occurred. Sixth, the correlations between the affective variables and the number of activities recalled, and students' learning on them were small or trivial, suggesting that judging the success of the visit experience should consider both cognitive and affective outcomes.

This study has demonstrated that affect associated with visits to centres such as CSIROSEC is measurable, that it is multi-dimensional, and that it persists. In contrast, the cognitive learning faded over time (Rennie, 1993), suggesting that affective outcomes may be more resistant, a finding consistent with other research on what visitors remember from museum and similar visits. Much other research has examined the effect of pre-visit instruction or other orientation activities, and consistently found them to be positively related to cognitive outcomes. The findings of this research suggest that affective outcomes also may be positively influenced by associated instruction. These results suggest that the visit experience needs to be put into the context of classroom learning for maximum benefit to be gained from the visit.

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STUDENTS' THINKING IN A CHEMISTRY LABORATORY

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ABSTRACT

Despite the almost mandatory inclusion of a laboratory component in the school curriculum very little has been reported about the effects of laboratory instruction upon student learning and attitudes. The present study was undertaken to investigate the thinking of students in a chemistry laboratory. An interpretive research method was adopted in collecting and analysing data gathered from observations, general interviews and stimulated recall interviews. Four high school students were studied during their participation in a week-long university summer school program. This study reports how the four students responded differently to the same laboratory experience.

INTRODUCTION

The inclusion of a laboratory component in science education had its origins in the 19th Century when chemical schools were established as training grounds for young practical chemists (Hegarty-Hazel, 1990). Since that time the rationale for including a laboratory component within a science curriculum has undergone many transitions. Hegarty-Hazel (1990) accounted for the origins and institutionalisation of laboratories for the teaching of science. Initially, training in practical skills was the principal goal; then there was a shift to teaching the scientific method. However, factors including a lack of resources and a shift in accepted philosophy meant that laboratory experiments became graded exercises from structured manuals. The educational reforms of the 1960s produced inconsistent and contradictory frameworks for science curricula resulting in teaching laboratories plagued with problems (Hofstein & Lunetta, 1982). Many science experiments in high schools required students to follow strict instructions, recipe-style. Deviations from the instructions were not tolerated lest the experiment might fail. This cookbook approach to science experiments has been linked to an objectivist view which apparently underlies much science teaching practice (Tobin, 1990a). Objectivists hold that knowledge exists independently of the knower and is transferred from an authority to a passive learner. Many studies report findings that question the effectiveness of traditional teaching methods and routine, passive practical work (Gallagher & Tobin, 1987; Tobin & Gallagher, 1987). The cookbook approach is not particularly effective in promoting conceptual understanding except for a very small proportion of pupils (Hodson, 1993). Evidence exists that suggests many students, even after successfully completing basic science courses, still misinterpret many of the scientific concepts ostensibly learned by them (Reif & Allen, 1992).

Ritchie (1994a) described constructivism as an epistemology which focuses on the role of the learner in the personal construction of knowledge. From this perspective learning is viewed as an adaptive process where the learner's existing knowledge is modified in response to perturbations which arise from both personal and social interactions (Wheatley, 1991). Recognition that students construct and reconstruct their own beliefs through a process of negotiated meaning (Driver, 1988) has highlighted the need to incorporate appropriate laboratory exercises that foster this adaptive process.

Roth (1994) reported that students were aware of the difference between open-ended inquiry and traditional laboratory exercises and that most students did not like the cookbook approach because the purpose of most steps remained hidden from them. Johnstone and Wham (1979) found that students "were able to think for themselves and be actively involved in planning their own procedures" when engaged in open-ended inquiry laboratory work (p.17). The present study investigated the responses of different students to a research project conducted along the lines of an open-ended inquiry.

METHODS

Purpose

Gallagher (1987) concluded that "Laboratory work is an accepted part of science instruction. Given its important place in the education of youth, it is surprising that we know so little about its functioning and effects" (p. 351). The purpose of the present study was to document student thinking during laboratory activities in a setting similar to that of practising scientists and to add to the now growing literature on the value and nature of quality laboratory instruction. In particular, this study focused on the thinking of four different students as they engaged in the same open-ended chemistry project.

Setting

The study was conducted in a chemistry laboratory at a university located in North Queensland, Australia. The university conducts summer schools where Year 11 students are invited to take part in a university experience program designed to introduce high school students to the atmosphere of learning in a university. A supervisor, not one of the authors, guided the students through their chemistry project. This supervisor was a university lecturer with a PhD in chemistry who also held a secondary teaching qualification. The students' comments suggested that the supervisor was very good at explaining processes clearly and his style appeared to encourage student questioning and participation. The students had exclusive access to a fully-equipped third year chemistry laboratory and a technician was available to provide all glassware, reagents and materials.

Subjects

All four subjects were female and had just completed Year 11 at their respective high schools. Two were from the same private school and two were from public schools in different rural towns. All four had voluntarily elected to spend the last week of their school term at the university summer school.

Wanda was particularly skilful during laboratory sessions. She not only revealed that she had considerable prior experience in school laboratories but also appeared to be reflective and articulate during interviews.

Betsy had very limited experience in laboratory work and never became completely comfortable with the apparatus. However, she made valuable contributions to the group work and was able to articulate her thoughts without much difficulty.

Sandy was quiet and serious and although she had limited laboratory experience she soon assimilated the necessary skills for the project. Through time she appeared to become more confident in her own abilities. She made valuable contributions to the group but had some difficulty articulating her thoughts.

Jane was bubbly and talkative but also displayed limited laboratory expertise. She admitted to lacking the ability for reflective thoughts. During interviews she had great difficulty in articulating or even remembering her thoughts.

Project description

The project involved the quantitative analysis of phosphate levels in various water samples using spectrophotometry. Two methods of phosphate analysis were used, a standard method and the Greenpeace method. Although the project was presented to students as a mini-research project, it was not strictly an open-ended inquiry. However, the students gradually assumed greater responsibility for their progress throughout the duration of the project. For example, on Day 2 the students figured out the best range of concentrations to use in order to construct the standard curve on their own, rather than follow a set of instructions, cookbook style. The supervisor did provide explanations for theories and concepts but led the students through the process by questioning and probing rather than by simple delivery of facts. Consequently the students' level of ownership with the project was high. As Wanda described her thoughts when the supervisor left the students alone to work: "It was sort of like a new experience and you get really excited. It's sort of like 'Wow, you know, let's see if we can do this work' ..."

At the first laboratory session on Day 1 the supervisor explained the theory relating to the measurement of concentration by absorption. The process of creating a calibration curve was also explained and the students were told they were to compare the two methods of phosphate analysis.

Following the pre-laboratory explanation, the students were then allowed to proceed at their own pace. The supervisor was constantly available for help during this time and often demonstrated the use of apparatus to the students. The students' first task was to construct a calibration curve according to the standard method. This task took the remainder of the first day.

On the second day the students used the Greenpeace method to construct a standard curve and determine the concentration of some known samples. This task took the most of Day 2. The supervisor was again available for student consultation but was progressively allowing the students to own the project themselves.

On Day 3, the students were taken on a field trip to the sewage plant to collect samples. Inflow and outflow samples were taken. When the students returned to the laboratory, they used the two methods to determine the phosphate levels in the samples. The supervisor was absent during this time and the students were self-directed with access to a technician.

On Day 4 the students worked on preparing a poster presentation of their project. The poster was part of a public display of all projects undertaken during the summer school. Again the supervisor did not participate to a great extent in this process and the students took responsibility for the content and layout of the poster.

On Day 5 the students assembled their poster presentation. The supervisor suggested that the students might wish to construct a visual display depicting the mixing of the reagents which created the coloured solution measured by spectrophotometer. The students embraced this idea and spent a great deal of time working out the mechanics of such a display.

By the end of the week the students had gained hands-on experience with the concepts of spectrophotometry, calibration curves, concentrations, serial dilutions, and analysis of water samples.

Data sources and techniques

A researcher was present as an observer for most of the time the students worked in the laboratory. There was minimal interaction between the researchers and students during observation. The major source of data was stimulated-recall interviews conducted over the week to access students' thinking. Two interviews, approximately 30 minutes in duration, were conducted with each student to yield eight interviews overall. The stimulated-recall interview technique has been used in process-tracing research to study the mental functioning of people at work in various task environments, including expert physicians (Elstein, Shulman & Sprafka, 1978), counsellors and their clients (Kagan, Krathwohl, Goldberg & Campbell, 1967), teachers (Marland, 1979; Yinger, 1980) and school students (Marland & Edwards, 1986; Ritchie, 1994b). The principal guidelines outlined by Marland (1984) were followed in the conduct of the interviews which were designed to encourage and facilitate disclosure of student thinking. All stimulated-recall sessions were audio-taped and transcribed for subsequent analysis resulting in 70 typed pages of data. In addition, students were observed by the researchers over the week to provide descriptive profiles and general interviews were carried out to reveal students' backgrounds, attitudes and expectations. Analysis of the data was carried out in an interpretive style, similar to that described by Erickson (1986). More specifically, assertions were generated from the data during the fieldwork phase and were later revised and modified through induction following a rigorous search of the data base. These assertions were checked against both confirming and disconfirming evidence to provide an interpretive analysis of the data.

DISCUSSION OF RESULTS

Two general assertions emerged from the analysis of the interview transcripts. Firstly, the lack of laboratory skills apparently interfered with conceptual learning and secondly, the relevance of the project promoted student interest. These assertions were supported by the descriptive profiles of the students generated by the observations and general interviews and will be discussed below with reference to students' experiences over the course of the project.

Assertion 1: Lack of laboratory skills interfered with conceptual learning

Wanda was by far the most competent in laboratory skills and frequently took the initiative on Day 1 when the students were setting up their first calibration curve and were unsure how to use the glassware. On Day 3 when the supervisor left the students to work on their own, Wanda was instrumental in keeping the momentum of the group going.

> I was thinking how we could get things moving pretty much and I thought that maybe there was some way I could get some more funnels from out the back so we could get the filtering under way more quickly so we could get stuck into our measuring ... I think I said we should try and find some funnels and stuff so we could make it quicker and they said it was a good idea so Jane and I went out the back and got some.

Wanda also sensed that her expertise with glassware exceeded that of her colleagues. For example when Betsy was using a pipette on the first day:

W: [laughs]
I: What's so funny?
W: She [other student using a pipette] was always asking what the measurement was ... I was used to using [pipettes] because I use them at school all the time ... they [the other students] just learnt how to use them and how to read them.

It appears that Wanda's confidence with glassware allowed her to concentrate on the problem-solving aspects of the project and she subsequently emerged as the leader of the group. The other students often asked her for advice and once she even explained to the supervisor how to use the pipette safety bulb correctly when he was floundering. Although these examples highlight Wanda's superior laboratory skills, she was not dominating and her style of group behaviour was more negotiated and democratic. For example when Wanda was describing her thoughts whilst the group was figuring out the next stage of the project:

I: So are these your thoughts or are you getting thoughts from others?
W: Yes, they'd be pretty much my thoughts and I'm also conscious of everyone else's to make sure it's sort of ... we have the same sort of type of feeling within the group, because if we don't, someone could get confused.

Many researchers (Friedler & Tamir, 1990; Johnstone & Wham, 1982; Rubin & Tamir, 1988) have argued that inquiry oriented laboratory work is cognitively demanding and that students may suffer 'information overload' of their working memory capacity. Expert scientists cope in these situations because they have highly developed technical skills which allow them to participate in genuine scientific inquiry unhampered by poor technique (Hegarty-Hazel, 1990). There are many instances where Wanda reported she was thinking about conceptual aspects of the project, for example when she was trying to work out the best set of serial dilutions to use:

> Yes I'm wondering "What's that? What's it represent?" I'm trying to think and remember back to yesterday and the other solutions that we made up. We measured the colour and the concentration of it and I'm trying to work it out in my head where exactly that was [on the curve] and whether we need to dilute it more or whether it was OK.

and also when she was using the graphs to determine the phosphate concentration:

> Just going through my head are the processes that we've been through, Greenpeace and the other one. I was remembering the results we got from them. We had to draw up graphs from that and I'm trying to think in my head which one was more linear, which was more accurate.

In comparison, the other students spent far more time thinking about getting the skills right and reported few instances of conceptual thinking. For these students, the use of pipettes was a new experience and clearly they were hampered during the early stages of the project by their inferior techniques. For example, Jane commented: "We do pracs [at school] but like we've never used a pipette. Pracs usually relate to our topic but we don't mix chemicals like we've been doing."

Jane constantly referred to her lack of ability in the laboratory. She was often heard to say "If something's going to go wrong, I'll be the one to do it" and frequently sought confirmation from other students or the supervisor before proceeding. Jane's lack of confidence in laboratory techniques led her to engage consistently in a number of strategies to avoid doing tasks that she felt unable to perform successfully. Johnstone and Wham (1982) identified a number of strategies students may engage in when learners suffer cognitive overload. Two strategies in particular - exhibiting random behaviour, in which she was "very busy getting nowhere", and becoming 'helper' or assistant to a group organised and run by others - were adopted by Jane throughout the course of the project.

Betsy was also hampered by her inadequate technique at the start of the project and also engaged in avoidance strategies. When Wanda was using the glassware to measure out reagents Betsy described her thoughts as follows:

B: More than anything I was sort of like organising everything for her [Wanda] to do, the measuring and things like that.
I: So Wanda was doing the hard work?
B: No, ... well, Wanda had the pipette.

and also when Betsy undertook the task of setting up a filtering apparatus she reported her thoughts as:

> I'd never learnt how to fold a filter paper and I was thinking I didn't have a clue how to do it and also I was putting water all over the filter and I was worried about that and I was being careful not to contaminate the stuff. I was just about to ask her [Wanda] when she finished washing.

Obviously Betsy's thinking was preoccupied with getting the techniques right. However, as time progressed Betsy became far more confident and, through experimentation, mastered many laboratory techniques:

> I was just checking if it made any difference like if I had it [the filtering apparatus] above the beaker. I lifted it up and checked if it flowed through and it didn't, not noticeably, so I just left it.

Sandy managed to assimilate the required techniques quickly and was fairly confident in using her new skills. The lack of technical skills did not pose the same barriers for Sandy as it did for Jane and Betsy.

Assertion 2: Relevance of laboratory investigation promoted interest

Consistent with a number of studies pointing to the popularity of laboratory work in the high school years (Dawson & Bennett, 1981; Keightley & Best, 1975) all four students in the present study reported a liking for laboratory work. There were several aspects of the research project which students reported were superior to their regular classroom practicals. All students reported a high level of interest in the research project exemplified by the following comments from Jane and Sandy:

J: I didn't know what to expect when I came but it's been better than what I thought it would be. I think it's good because it's practical as well and you don't do things like this at school.

S: The last term we haven't done a lot [of pracs]. We've been learning more about the periodic table and molecular shapes and things so I haven't really done any pracs for about the last term, which is pretty boring ... It's different to what you do at school. At school you're more thinking about the work you are doing. And it's more working out problems, it seems more structured and you have set questions.

Fordham (1980) suggested that interest in laboratory work would be stimulated by increased cognitive challenge. Current science teaching may fail to engage students cognitively by favouring teacher-driven cookbook style exercises. Students subsequently regard the laboratory as "an alien environment of forbidding rituals, with little relevance to everyday life" (Hodson, 1993, p. 92). In contrast, the students in the present study frequently made reference to the relevance of their research project to "real life".

B: I didn't realise that it was this interesting. I liked chemistry at school but you don't actually see what the chemists do in real life, how they research and things like that.

S: The pracs you do at school don't have any purpose. They're fun but they don't have a purpose. Mostly [the project's] been pretty good ... There's a purpose in what we're doing. It's not just at school, sort of thing. You're researching something and so it's been good. It makes me like chemistry more and getting away from the classroom situation.

The students readily identified a distinction between the type of laboratory experience offered at school and that offered by the present research project. As well, all students reported a preference for the less structured approach of the research project. This evidence supports the claim by Hodson (1985, p. 44) that "much practical work in school is aimless, trivial and badly planned."

Wanda appeared to be very interested in the project and in analytical chemistry as a whole. When the laboratory technician happened to show the students a water sample from a sugar mill, Wanda keenly listened and asked questions:

> I was quite interested in this sample that she had because it came from a sugar mill and where I come from it's like pretty much cane and everything. My dad drives a harvester and is closely related to the cane industry anyway and I was quite interested because we're not educated much on what other metals or whatever you call it that is in samples and stuff so I was quite interested in what she had there.

In addition to high interest levels, the students reported that they welcomed the opportunity to relate theory to practice.

B: In school we don't get to practically use a lot of the ideas we're taught and a lot of stuff is more clearer [sic] now because you can see it in real life. You learn about theories and that and you can't put it into practice but here we've been using the machine [spectrophotometer] and we've learnt a lot we don't practically think about. When something happens, you think "Oh yeah, so this is what they've been talking about" - things like precipitation.

Atkinson (1990) reported that in school science the laboratory appears not to be providing the link with theory which had been expected. Constructivists maintain that learning is an interpretive process, as new information is given meaning in terms of the student's prior knowledge. Open-ended laboratory experiences allow students to learn with understanding (Tobin, 1990b).

The concept of working intensely on a project over a period of time appealed to all students and most referred to the freedom of time the research project allowed.

S: The stuff we do at school are pracs that can be done in half an hour. I probably enjoy this [project] more.

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B: We had time to get to know each other and do our work at the same time ... Even if it was spread over more time, we could have done a lot more with it [the project].

Insufficient time to complete laboratory work is a common complaint in practical classes (Fordham, 1980) and one of the benefits of a research style project is the luxury of time. This luxury not only allows an experiment to be completed, but also affords the students plenty of time and opportunity to "reformulate their ideas, and to consider reasons for modifying and changing their frameworks of understanding" (Hodson, 1993, p. 111).

CONCLUSIONS

The 'Science For All' catch-cry currently popular in science education advocates making science accessible and meaningful to all students, not just for an elite group destined for a career in science. A commitment to science for all requires that science curriculum, teaching and assessment take into account student diversity and ways of coming to understand science. Data presented in this study suggest that some students are not suited to the open ended inquiry approach at the same time or at the same level. In his study of a high school laboratory course that was different from traditional science instruction Roth (1994) reported on the remarkable ability and willingness of students to generate research questions and to design and develop apparatus for data collection. Surprisingly, despite studying a total of 46 students, no instances where students failed to generate appropriate research questions or struggled to come to grips with the processes or concepts involved were reported. Roth appears to assume that the open-ended structure is best for all. Our study suggests that different students respond differently to the same laboratory experience. Mulopo and Flower (1987) have also shown that different styles of laboratory work produce different learning outcomes according to the developmental stage of the child and Hodson (1993) cited work by Strehle which suggested laboratory work produces much greater variation in individual performance than other teaching and learning methods. Hodson's (1993) call for researchers to focus more sharply on what students are actually doing promises to yield further insights into the pedagogic value of practical work.

This study identified two contributing factors for the differential response exhibited by students to the same laboratory project. Firstly, a lack of laboratory skills interfered with conceptual learning. As discussed by Friedler and Tamir (1990), inquiry oriented laboratories appear to be too difficult for many students. More specifically, demand for formal reasoning and the cognitive overload which results from the need to apply intellectual skill, practical skills and prior knowledge simultaneously provide substantial barriers to successful inquiry. Johnstone and Letton (1989) warn that since working memory capacity is limited, students need to control the amount of information they process. Hegarty-Hazel (1990) advocates teaching of procedural and substantive knowledge prior to any inquiry exercise in a structured and sequenced program. In contrast, Hodson (1993) favours on-the-job training in technical skills, perhaps with some kind of basic familiarisation program. Our results suggest that neither approach would serve the needs of all students. Instead, exposing students to a variety of learning situations is probably more likely to accommodate student diversity and satisfy the science for all policy.

The second contributing factor to the differential response in the students was that relevance of the research project promoted interest. All students reported a high level of interest in the project but for different reasons. Obviously there are many aspects to be considered in arousing and sustaining students' interest in a laboratory experiment.

Our study has highlighted the benefits of laboratory activities which are both relevant to students and designed to match student readiness for open-ended inquiry. The impact of the students' experience with open-ended inquiry on school learning will be the subject of subsequent investigations.

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DATA HANDLING IN THE PRIMARY CLASSROOM: CHILDREN'S PERCEPTION OF THE PURPOSE OF GRAPHS

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ABSTRACT

The National Curriculum programme of study for Science 1 in England and Wales states that pupils should be encouraged to develop investigative skills and understanding of science through activities which "promote the search for patterns in data and the ability to make simple predictions based on findings" (Department of Education and Science, 1991, p. 14). In order to search for patterns children have to first understand the purpose of graphs and the relationship of variables. This paper describes some of the preliminary findings of the Data Handling in Primary Science Project. The majority of primary school children, involved in a data handling project (Rodrigues, 1994), see graphs in science as an end product to be displayed. In addition the children appeared to have a very limited understanding for the type of graph employed being determined by the variable involved. Furthermore whilst some of the children were able to read information from a graph, the language used had a marked effect on cueing the response.

INTRODUCTION

The aim of this paper is two-fold:

- to add support to the notion that children of primary school age appear to understand the idea of fair testing; they know what to change, what to keep the same and what to measure, and they can employ commendable graphing skills.
- to indicate that children of primary school age do not fully understand the relationship between the variables and consequently the type of graph needed to be drawn, and are therefore unable to appreciate fully the data their investigation has generated.

Data handling and the National Curriculum for Science in England and Wales

The National Curriculum for Science in England and Wales (Department of Education and Science, 1991) contains four statutory attainment targets, one of which is concerned with scientific investigations. Underpinning these science investigations are fundamental characteristics of procedural understanding which have been termed 'concepts of evidence' (Duggan & Gott, 1994). One of these concepts of evidence is the concept of data handling. This involves understanding that there is a link between graph representation and the type of variable that they represent and understanding that tables and graphs can provide patterns that explain the behaviour of variables (Duggan & Gott, 1994).

The National Curriculum for Science in England and Wales (Department of Education and Science, 1991) demands that at each Key stage, children should attempt to discern relationships or patterns in their investigation findings (Austin, Holding, Bell & Daniels, 1989). Indeed, the School Curriculum and Assessment Authority (1994) states that at Key stage 2, children (aged 7 -11), should be encouraged to search for patterns in data, and to interpret the data against the demands of the problem. This implies that children have to design investigations that require a systematic approach involving simple variables in a fair test. Within the fair test approach the establishment of causal links between the variables is considered an important scientific skill because independent and dependent variables define a scientific investigation.

If patterns are to be identified, so that the investigation can be evaluated and communicated by the child, then the type of graph used is important. This in turn is dependent upon the variables in the investigation. The character of the data and the form in which they are handled by children is an important consideration, if the data are to be scanned for possible underlying 'causes' of perceived behaviour.

If the investigation lends itself to the construction of line graphs because the variables are continuous, but the child constructs a bar graph, because it is easier to do so, then the value of the data collected is restricted. Consequently the information construed from the data will be limited and interpretation becomes problematic.

Foulds, Gott and Feasey (1992) stated that, unlike the notion of a fair test, presenting and interpreting findings does not appear to have been established primary classroom science practice. Children report and record their findings in an everyday way rather than use tables and graphs. For example, a recent report (Foulds, Gott & Feasey, 1992) indicated that 91% of year five children report their investigations sequentially and 2% included a critical evaluation. Children need to understand why they are gathering and presenting data, but many children lacked this understanding. Indeed, Phipps (1994) suggested that at Key stage 1 many children are not given the opportunity to explore the process or purpose of handling data. Furthermore Foulds, Gott and Feasey (1992) also stated that at Key stage 2, 1.86% of the children drew line graphs and 12.6% drew bar graphs, regardless of whether this was the best way to present the data.

The Assessment of Performance Unit findings (Department of Education and Science, 1988, 1989) indicated that the form of presentation of variables could affect the child's performance in interpreting the information. Therefore it is important that children understand the value of graphing skills both in terms of assessing their performance and in terms of developing scientific process skills. Using line graphs to explore the existence of relationships between variables is an important skill that children are required to develop in primary school science (Austin, Holding, Bell & Daniels, 1989; Phipps, 1994; School Curriculum and Assessment Authority, 1994).

The 'picture' presented by a line graph has the potential to enhance children's interpretation of their investigation findings. Properly interpreted graphs enable relationships that were hidden or less obvious in the results table to become more obvious and open to inspection. Austin, Holding, Bell and Daniels (1989) indicated that a sizeable proportion (30%) of twelve year old children made no useful sense of either the graphs or the data available to them. These children may have no idea how graphs can help uncover a relationship between variables. This may be due to the fact that customarily children are taught and expected to practice the low level mechanics of plotting particular graphs when given a table of information (Jackson, Edwards & Berger, 1993). In primary school science lessons there is little time available to focus on issues of interpretation and evaluation for purposes of modification and extension of their investigation. If the data acquired during an investigation are not transformed into communicable information from which trends and patterns can be ascertained, then the graph has limited value and the children may as well continue to report their data in the form of prose.

THE DATA HANDLING IN PRIMARY SCIENCE PROJECT

The Data Handling in Primary Science Project involved 22 schools in the North East of England. The project was initiated to develop primary science curriculum support material for scientific investigations, in particular, data handling, directly linked to the National Curriculum (Rodrigues, 1994). The main sample in this project consisted of one class of nine special-needs school-children (aged 9-16), one class of 23 Year 3 (aged 7-8) children and 355 Year 5 children (aged 9-10).

The pre-questionnaire, the main source of data in this paper, was completed by 378 children; they were given a questionnaire to complete 3 to 6 weeks before the resource material was tested. It contained three main sections. The first investigated children's knowledge of plastics because the research was partly sponsored by I.C.I. and the resource materials involved plastics. The second section investigated children's abilities to construct, interpret and evaluate graphs and tables. The third section sought children's understandings for why school children and scientists used graphs and tables. The questionnaire codes represent the area, the school, the child, the age of the child and the gender of the child. Information in this paper was also derived from interviews with four children. The teacher was asked for an able student, two average students and one below average student. These children worked with the researcher on investigations described in the resource material (Gray, Rodrigues, Simpson & Sowden, 1994). The children (aged nine, two boys and two girls) were withdrawn from lessons for approximately an hour over a period of four weeks. During this time the children undertook two activities from the resource which required bar and line graphs to be drawn. Two weeks after the final lesson, the children were separately and informally asked about the line graphs they had drawn during the sessions. The researcher asked them to explain how and why they constructed the graph and to interpret the graph.

FINDINGS

Preliminary findings from the project indicate that the low level mechanics of graph construction and presentation is the main focus of data handling activity in the primary science classroom. Generally the questionnaires indicated that children's overall performance in constructing bar graphs is better than their performance relating to line graphs. Yet, the School Curriculum and Assessment Authority (1994) suggests that teachers and students will need to focus on both types of graphs in science. They stated that children should be taught "to use tables, bar charts and line graphs to present results...to use results to draw conclusions ... to say whether the evidence collected supports any prediction made" (p. 8). However, this aspect is not the focus of the findings. Instead we consider the children's rationale and understanding for using particular types of graphs in science.

An experiment was described in the questionnaire in terms of two fictitious children wanting to find out how fast a cup of tea cooled down. The fictitious children explained that they placed tea in a plastic cup and measured the temperature of the tea every two minutes. They then presented their results; one opted for bar graphs and one for line graphs. The children completing the questionnaire were then asked to identify which type of graph they would draw if they conducted a cooling tea experiment. Their responses are summarised in Table 1.

The children were asked to justify their responses and their justifications were also categorised (Table 2). These categories were predetermined but added to when and if a child's response did not comply with any of the categories. The categories were determined originally by the researcher and three teachers checked the categories and responses. (Please note the children's words are represented as written by themselves, with no corrections for grammar or spelling.)

TABLE 1
TYPES OF GRAPHS CHILDREN WOULD DRAW FOR A COOLING TEA INVESTIGATION.

Category	Percentage of children (n=378)
No response	8%
Line graph	16%
Bar graph	52%
Both graphs	24%

TABLE 2

CHILDREN'S JUSTIFICATION FOR THEIR CHOICE OF GRAPH

Category	Percentage of children (n=378)	Examples to illustrate the categories.
No response	15%	Blank space or child wrote 'do not know.'
Continuous variable	0%	
Aesthetic/affective	20%	Because it looks betur. (T16/19/8g)
Ambiguous	12%	I just gessed because she is mearing (N18/21/9g)
Easy to do	45%	Because it is easyer to do. (N18/17/9b)
Same information	8%	Because I think there both the same. (N12/5/9b)

The majority of children did not perceive the variable under consideration to be continuous and consequently did not select a graph that best suited this type of data. In another question, children were given the same information, involving continuous variables, in the form of a line graph and a bar graph. They were asked to read data off a point located at the intersection of two labelled scale divisions (i.e. a value that required them to use both scales but was on a main division, e.g. what was the temperature of the water after 30 minutes?). Less than 8% used a line graph. The majority used a variety of strategies involving the bar graph to provide a sensible response.

If children do not consider the importance and the distinction between the variables, then they are unlikely to bring the variables together in causal statements. This means that they are unlikely to 'describe' the relationship between variables although they might well be able to read off the graph and provide numerical responses. Indeed interviews with the children indicated that they were able to read off points on the graph. The four children interviewed were asked if they recalled drawing the graphs and asked to recount the occasion. The children could clearly recall drawing the line graph and were able to describe the activity which lead to them constructing the graph.

The four children were then asked to read data off a discrete point, (i.e. a value that could be read off a numbered point, for example what was the final temperature of the water in cup one?) They were asked to read data off a point located at the intersection of two labelled scale divisions. The children were also asked to read data off a point located at the intersection of minor divisions, (i.e. a value that required them to use both scales but involved the smaller divisions on the scale, e.g. How long did it take before the water had cooled to

27°C?, with the response being 10½ minutes.) All the children were able to read and provide responses that were accurate given the graphs they had drawn.

The four children were also asked what was the temperature of the water at the start of the investigation. Three of the four children appeared to be concentrating very hard, then looked forlornly around the room, and stated that they could not remember. Later, but during the same interview, when the question was rephrased to "What was the temperature of the water at zero minutes?", all four children were able to respond correctly. This could indicate that the language and context in which the question is framed, clues the child into a response. In the questionnaire, children were also asked why scientists draw graphs. This was an attempt to probe whether children had an understanding of the purpose of graphs in science. Table 3 provides an overview of their responses. Once again, the illustrative examples of children's comments have not been amended for their spelling or grammar.

TABLE 3
CHILDREN'S UNDERSTANDINGS FOR WHY SCIENTISTS DRAW GRAPHS

Category	Percentage of children (n=378)	Examples to illustrate the categories.
No response	27%	Blank space or child wrote 'do not know.'
To show patterns	1%	So you can see how many people liked elephants and that sort of thing. (T1/14/10g)
Aesthetic reasons	0.5%	Becase the like drawing. (N12/5/9b)
Ambiguous	17%	To colure what the have got of jigsaws so they do not miss a peace. (T16/6/8g)
Easy to do	13%	Because it would save them writing everything and their easy to draw. (T14/15/9g)
Easy to read/present information	42%	I think scientists draw graphs because it is a good way of recording your answers and it is quick and easy to read. (T14/22/10g)

DISCUSSION

If children are to meet the criteria set out by the National Curriculum in Science in England and Wales (Department of Education and Science, 1991; School Curriculum and Assessment Authority, 1994), they have to be able to present their data in suitable forms which aid their quest for patterns and trends. This in turn requires children to be able to select graphs appropriately and to be able to read information from graphs. Data handling requires not only the ability to read information from a graph but an understanding of the function and purpose of a graph, so as to inform the design and execution of science investigations.

The children interviewed were able to read scales that involved both major and minor grid lines. Questionnaire responses indicate that many children did not read the scales accurately and therefore could not provide a correct value. However, the reasons for this (inability to count, development of counting strategies which foster errors, 'sloppy' readings etc.) have not been determined. Neither the interviews not the questionnaires provided an indication of the strategies children used to read these scales.

Children who completed the questionnaire appeared not to realise that variables determine the type of graph that best fosters interpretation of the collected data. In the sample, 45% of the children would choose to draw a line graph or a bar graph because it was easy for them to do. This may be due to children receiving more experience and practice of bar graphs in primary schools. This is problematic, because the review of the National Curriculum by the School Curriculum and Assessment Authority (1994) has led to statements proposing that children should be taught to use bar and line graphs, and determine whether the evidence they collected provided any support for the prediction they made.

The children in this project did not select the line graph because they were able to distinguish the variables as either continuous or discrete. Therefore the children may not understand the nature of continuous or discrete variables and do have an understanding of the particular variable for the 'cup of tea' experiment. This would imply that the children do not understand the value or purpose of bar or line graphs or indeed the relationship between variables.

Only 1% of the pre-questionnaire sample indicated that scientists use graphs to illustrate patterns or determine trends. Therefore whilst large numbers of children in this project were able to read data that corresponds to particular points on the graph, the vast majority perceive graphs as visual presentations of information. Even though the National Curriculum in Science in England and Wales (Department of Education and Science, 1991) has advocated the importance of data handling in science investigations, there appear to be many children who are still unaware or confused as to the purpose of graphs and tables in science. In the pre-questionnaire sample 42% of the children indicated that scientists draw graphs because they are easy to read or are useful in presenting information. Whilst displaying work is a commendable purpose, graphs are used in science to do more than present information. Graphs are used to help determine trends and patterns, to evaluate investigations and to identify relationships between variables.

If the graph chosen for an investigation is inappropriate, and takes no account of the type of variable, then the graph loses much of its power and the purpose is lost. The children in our sample, have obviously been taught the mechanics of drawing graphs but have yet to understand the value of these graphs in their science investigations. Children who do not identify relationships in their graphical data show a lack of awareness of the meaning of graph axes. In addition the purpose of a graph and data handling is limited to the ability to demonstrate the practical skill of constructing a graph and the mechanical ability to read minor and major grid marks.

CONCLUSION

If graphs and tables are taught simply as algorithms, then the ability to tease out explanations from the patterns and trends observed will be restricted. If the children do not understand the purpose of graphs then data handling will not impinge upon the design or the execution of the investigation. Furthermore, if the children acquire the skills of drawing graphs and tables mechanically they may learn the skill in isolation, perform the skill as an end in itself and not acquire an understanding of the scientific procedure. Teachers and children have to bridge the gap between performing mechanistic skills resulting in display work, and incorporating data handling as a vital component and procedure of a scientific investigation.

From an assessment point of view it is important to note the impact of language, signalled in this paper, in prompting a response from the children. Minor changes in the use of language resulted in quite different perspectives of children's skill. Three of the children interviewed associated "temperature at the start of the investigation" with having to recall the figure from memory, whereas being asked about the temperature at zero minutes resulted in them using the graph. Therefore there are implications with regard to assessing children on their ability to perform particular graphing skills. The choice of question will have a crucial role for those who develop Standard Assessment Tasks. These issues need to be investigated much more vigorously and in more detail.

There is an assumption in science education that the process approach to school science will promote elements of scientific methodology, during which the child will practice skills such as hypothesising and interpreting data. From the school science point of view, this means encouraging children to design experiments to help them ascertain and determine relationships, not simply teach them the mechanics of graph work. Teachers and the curriculum have to encourage the children to use their science knowledge to make sense of the data and to encourage the children to understand the need to draw different types of graphs depending on the variables being considered to best illustrate their data and hence interpret the resultant information.

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HAVE YOU GOT ANY CHOLESTEROL? ADULTS' VIEWS OF HUMAN NUTRITION

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ABSTRACT

The general aim of our human nutrition project is to develop a health education model grounded in 'everyday' or 'situated' cognition (Hennessey, 1993). In 1993, we began pilot work to document adult understanding of human nutrition. We used a HyperCard stack as the basis for a series of interviews with 50 adults (25 university students, and 25 adults from off-campus). The interviews were transcribed and analysed using the NUDIST computer program. A summary of the views of these 50 adults on selected aspects of human nutrition is presented in this paper.

INTRODUCTION

The first part of the title is a question asked by Leonor, a nursing mother, during an interview about nutrition. Nutrition is a field we have selected in our continuing investigation into the public understanding of science and technology.

This paper describes one aspect of a continuing research project on the public understanding of science and technology (Schibeci, 1988, 1989) at Murdoch University. The area of health is one with a significant science and technology dimension. Within the health field, human nutrition is especially important. For example, a recent community survey reported in *Healthway* (Western Australian Health Promotion Foundation, 1993) found that nutrition was the most important health promotion issue, mentioned by 18.6 % of the respondents, followed by smoking (16 %) and physical exercise (11 %). The report commissioned by the Better Health Commission, *Towards better nutrition for Australians* (English, 1987) noted that: "The Commission considers nutrition ... to be an area where the definition of national health goals could have immense benefit". The booklet, *Food and nutrition policy*, by the Commonwealth Department of Health, Housing and Community Services (1992) begins with the statement: "Sound nutrition is a vital component of health" (p. 1).

Human nutrition is an interesting area because adults can be quite knowledgeable about food. To treat adults as 'ignorant', as in the cognitive deficit model (Layton, Jenkins, Macgill & Davey , 1993, p. 125), is likely to be counterproductive. Another feature of this field is the lack of consensus about what constitutes healthy living; this is due, in part, to the fact that humans can vary widely in their responses to particular nutrients. This makes it difficult to make unequivocal predictions and definitive prescriptions for better health.

The *general* aim of our human nutrition project is to develop a health education model grounded in 'everyday' or 'situated' cognition (Hennessey, 1993). The *specific* aim of this paper is to present a summary of the views of the 50 adults in our sample on a range of issues related to human nutrition.

PREVIOUS STUDIES

Human nutrition and nutrition education

Mennell, Murcott and van Otterloo (1992), in an introduction to the sociology of food, observed that few sociologists have, until recently, considered food and eating worthy of serious intellectual interest. They hypothesised that this may have been a consequence of "the sheer biological necessity ... to take in nutrients at regular intervals" and also of the "importance of meals and commensality in the social life of most human societies" (p. 1). This early neglect has been replaced by much recent interest, as the literature attests.

Nutritionists have long recognised the importance of the field; the size of the nutrition education literature is a manifestation of this. Johnson (1985) reported a meta-analysis of the nutrition education literature which located 673 studies; of these, 303 had "useable" research findings. He concluded that nutrition education results in : (1) a "marked increase" in nutrition knowledge; (2) "some increase" in positive attitudes to eating nutritiously; and (3) "constructive changes in patterns of food consumption". These results, according to Johnson, "have been basically consistent throughout 74 years of research". He also commented that nutrition education research was characterised by a "failure to base the research on theoretical models" (p. 20). This position is reinforced by an analysis by Achterberg and Clark (1992) of 346 nutrition articles, of which only 23.5 % cited the use of a theory or model in the research. Such theoretical work is essential in helping us to understand the processes which result in people's nutrition knowledge, attitudes and practices.

The literature also suggests that some nutrition experts appear to believe that communication is the problem: if only the correct form of communication can be identified, adults would "take on board" their expert messages. This view is consistent with the 'cognitive deficit' model described earlier. The recently-published report containing dietary guidelines for Australians (National Health and Medical Research Council, 1991, p. ix), for example, notes that: "Nutrition is a complex science and communication of its messages demands more information than can be given in brief statements". The problem is seen as one of finding the best way to impart information. Clements (1986), in a history of nutrition in Australia, noted the common view, that to get changes in nutritional practices, all you had to do was "to tell people to do it" (p. 229).

As indicated above, our work has been informed by the relatively new theoretical framework, **situated cognition**, which views learning as "a process of enculturation or individual participation in socially organised practices, through which specialised local knowledge, rituals, practices, and vocabulary are developed" (Hennessey, 1993, p. 2). This theoretical framework offers much promise in helping us to understand how adults develop everyday nutrition practices.

Pilot nutrition project

We began a pilot nutrition project (funded by a Murdoch University Special Research Grant) by exploring ways which would allow us to document some of the processes used by adults in transforming 'expert knowledge' about human nutrition. Among the processes adults might use in reconstructing nutrition knowledge are the following: (1) relating the new information to prior knowledge and practices; (2) comparing and contrasting the new information when it is described in varying modes (tabular, graphical, prose); (3) testing hypotheses, such as observing the effect of changes in their diets ;. (4) comparing experiences with those of friends, families and neighbours; and, (5) discussing the new information with others, such as medical doctors, friends, fellow club members and so on. At this stage of our study, we have dealt with items 1, 2 and 4 only. The other possible transformation processes require systematic observations which will build on this pilot study. Further background to the project is provided in Schibeci and Wong (1993).

METHOD

Sample

Respondents in this study were volunteer university students (18 female, 7 male), who made themselves available in response to an invitation given during one of their lectures. These students did not constitute a random sample, nor are they representative of university students as a whole. Ten were classified as 'science' (with two or more years of tertiary level science education) and fifteen were classified as 'non-science'. The students were interviewed in rooms on campus. The interviews were conducted generally without interruptions and in quiet conditions, suitable for audiotaping.

Three off-campus groups responded favourably to our search for further volunteers: eight female members of a yoga class; eleven members of the Nursing Mothers' Association; and, six male cricketers. They were all interviewed in their own homes, sometimes in less than ideal conditions.

Data

The data source is a set of transcribed interviews with the 50 adults in our sample. The format of the interview and the types of questions included in the questionnaire evolved during the process of interviewing the pilot sample (25 university students). In each interview, we gave respondents access to a HyperCard stack (on a Macintosh Powerbook 170) which we created for this study. This stack, which we referred to as a 'dictionary', is a database of nutrition information taken from many sources. A particular entry may include items taken from the following: a nutrition textbook, a biochemist, a medical article, a women's magazine article, a newspaper article, a pamphlet from the Health Department, an athletics magazine article, a health magazine (*Well Being*) article, advertising from a CSR dietitian, an article by a naturopath and so on. The source of the nutrition information is identified, so that when respondents browse, they know the source of the information. Worsley (1992) has shown that different sources are rated differently by respondents. The stack is described in more detail in Schibeci and Wong (1994).

Following the trial with the pilot sample of 25 university students, we refined our procedures (we used a paper questionnaire, together with access to the nutrition 'dictionary') and interviewed 25 adults from three different off-campus groups: nursing mothers, Yoga club members and cricketers. Responses to open-ended questions in the questionnaire were audiotaped and transcribed. Most interviews took about 45 minutes. All 50 interviews were conducted by the same research assistant who had experience in nutrition education.

RESULTS

Respondents raised a broad range of issues related to human nutrition. In this paper, we present an analysis of our respondents' views on the following topics: cholesterol, fat, Body Mass Index (BMI), and iron, as these were the most frequently mentioned by our respondents.

Cholesterol

Cholesterol and its links to fat and heart disease have generated much controversy in the mass media. We did not ask specific questions about cholesterol but many respondents, some of whom had family history of high cholesterol and heart problems, were concerned enough about this issue to consult information about cholesterol in the nutrition dictionary. In particular, an abstract on cholesterol levels taken from a Heart Foundation publication attracted greatest interest; on the average, they spent about 100 seconds reading it.

A common pattern emerged: many terms were remembered (from the media?), but with little understanding. For example, Janet (a nursing mother) said

> Animal fat contains high levels I think or are they high in HDL which I think are ... I don't know what it stands for, the liver proteins or something like that. They are high in HDLs and from something I read about how the LDLs help the fats go through the cell walls and back again and stuff like that or take them away, I don't know I can't remember all that now.

Other technical terms which were not understood were: mmol/l, lipoprotein, HDL and LDL. This finding is consistent with results of studies of concepts held by school students (see, for example, Schibeci, Fetherstonhaugh & Griffin, 1993).

In general, most respondents were aware of the relative level (high/low) of cholesterol in foods such as prawns, shellfish, fat from meat, and eggs. Maria (a nursing mother) who reared her own ducks and chickens, read the article on eggs in the dictionary and was impressed by the claim that free range eggs are healthier than battery eggs. However, she did not question the basis of this claim.

Several respondents believed correctly that our body makes its own cholesterol. Janet (a nursing mother) asked whether it is true, "if we are putting cholesterol-high animal fats in our body then our body is not making it itself".

Body Mass Index (BMI)

Body Mass Index is used by nutritionists to advise adults of the status of their weight (Stanton, 1992; Llewellyn-Jones, 1993). The BMI is not a suitable index for children (as they are growing) or for athletes (who may be 'muscle dense'). BMI is calculated by dividing a person's mass (in kilograms) by the square of the height (in metres). For example, a 1.8 m person weighing 75 kg would have a BMI of 23. According to Stanton (1992, p. 40), a BMI value "from 20-25 has been found to be most consistent with good health. If your BMI is above 25, you are probably too fat; if it is below 20, you are probably too thin".

We were interested in our respondents' ability to work out their BMI, and their reaction to this knowledge. They were given both the formula and the typical BMI weight-height chart; they could choose either method to determine their BMI.

A number of the respondents had some difficulty with the mathematical operations involved in determining the BMI. For example, Pam (one of the university non-science students) did not realise the significance of the division line in the BMI formula (she asked if it meant 'multiply'). Joan (another university student) did not understand that the height needed to be squared. Five other people did not know their height in metric units, and seven did not know how to square the height. Once these difficulties were explained, most could calculate their BMI correctly.

Five people had some difficulty locating their BMI on the chart. A major problem arises from the BMI values printed at the right hand side of the chart. More than seven people looked at these printed values and put their BMI on the right hand side or looked across the *straight* *lines* from these BMI values instead of the curves for the *range* of values. To others, the labels such as 'obese' were helpful to alert them to the wrong points they put on the chart. Only one particularly perceptive nursing mother (Maria) commented that one could locate one's position on the chart using height and weight, without doing all the calculation.

On the whole, most respondents felt that doing the calculation did not add much to what they already knew about their weight or what they would do with their lifestyle. They felt that one must feel comfortable with oneself, as commented by Jeremy, a cricketer:

> I don't know that it makes a big difference where you are on the chart, it is more how comfortable you feel with the way that you are. ... I wouldn't place much importance on that chart. It would just be an interesting thing.

Fay, a student, who had difficulty with working out her BMI, said: "Well what I would do, would probably be not much, because my lifestyle pretty much makes me happy."

Other respondents linked BMI with diet and exercise and commented on what they *should* or *would* do. For example, Fay said that a high BMI value meant that people were "either eating too much, or not exercising enough", and she *should* "eat more regularly, and in more balanced terms, probably a lot more fruit and probably exercise is about a hundred percent more". Glenn, one of the cricketers, echoed this view: "I'm eating well, that my exercise is good". Scott, another cricketer, said that his BMI value (22.5) indicated that "I'm doing something right fitness wise or eating wise." Jason, also a cricketer, said his BMI suggested he was "almost verging on the overweight category", but added "I'm not sure of any immediate things I can do to change it". Jeremy, a cricketer, took BMI to be an index of "mainly how much fat I'm carrying I guess". Leonor, the nursing mother whose question is the title of this paper, said she was thinking of going to Easy Slim because her BMI value was in the 'overweight' category. Heather, also a nursing mother, said: "I feel the right size and shape but I am not necessarily happy with the shape of my body".

Interestingly, only two respondents (both students, Marilyn and Tom) questioned the validity of the BMI as an index of good health. Marilyn said that "you can't really use it for everybody, just the average person", and gave a number of reasons (bone density, musculature, metabolism) why BMI might not be an appropriate index in every case. Tom said you needed more information about 'body type' and 'frame size' to make sense of the BMI value.

Fat

Responses to questions about fat in the diet also revealed a lack of understanding (from a nutritionist's perspective). For example, Scott (a cricketer) said,

> Things like fats that must be in margarine that has got a lot of high fat content compared to butter. So the fat content that is in margarine must be a bad sort. . . and I think in skin on chicken and stuff like that has a pretty high fat content.

Christine (a nursing mother) indicated that she understood nutritionists' advice on fat:
"A certain amount of fat is an important part of a nutritious diet with an emphasis on the unsaturated fats." She continued, however, "You should have enough [fat] to provide essential amino acids and vitamins that are in the fats." This latter observation is not one nutritionists would consider correct.

Some of the conflicting advice picked up by adults is highlighted in the observation by Karina (a nursing mother) about the various types of fat:

> There are people who try to tell you that polyunsaturated fats are the way to go and then there are also various schools of thought about mono-unsaturated fats being a whole lot better for you in some ways.

Janet (another nursing mother) highlighted the problems in providing simplistic advice. She observed that

> The amount of fat that our body needs for optimum health is probably variable for each individual and I dare say it would be a very difficult thing to assess how much fat each person needs and what is best for each person.

Iron

A few people made comments about the nutrient, iron, although this was not a specific issue raised by us. They commented that there was a "need to take mineral supplements or iron supplements or something if a person is feeling pretty low and down" (Scott, a cricketer). Clara, a nursing mother, said that broccoli and lettuce (which appeared in our diagram of a range of foods) "had some iron in it though it is harder for the body to absorb from vegetables"; she also noted that it was desirable to get iron from foods "rather than having to rush to the chemist and get a bottle of...iron". The complexities of iron absorption were noted by Heather, a nursing mother: "increased amounts of oat bran may inhibit the uptake of ...iron". Janet, another nursing mother, said that the iron in spinach was "not as easily absorbed by the body" when spinach is cooked. Another nursing mother, however, said "broccoli and other leafy vegetables help absorb iron more easily". Many of the respondents commented that red meat was a rich source of iron. Jessica, a student, observed: "I think red meat is a good source of iron even though you can't ingest it, it actually rots in your stomach". Another student observed, "Vitamin C prevent colds in large doses and assists in iron absorption."

Coralie, one of the students, said she became a vegetarian because, as a single mother, she could not afford meat; however, her daughter, now fourteen years old, had adopted a vegan diet, and she was concerned about her daughter's iron levels. Interestingly she said she would not go to a dietitian because she believed her views would not be respected: she would be told what was good for her, in her view. Clearly, this is an example of the 'cognitive deficit' model in action.

Credibility of sources of information

Some of our student sample requested the sources of information to be provided in the first version of the dictionary. These sources were identified in the final version of the dictionary used with the community groups. As expected, respondents had greater faith in information taken from the National Heart Foundation or the NH & MRC than from newspapers or magazines. Heather (a nursing mother) put it in this way, "Media reports didn't instil confidence in its truth or otherwise ... Information could be misquoted or misinterpreted in newspaper articles." On the other hand, Maria, another nursing mother, said: "When you find something that you agree with, you are not that concerned of where it comes from but who wrote it."

CONCLUSION

Scientists' most common remedy for 'ignorance' is more effective forms of science communication, such as better school science courses, the use of television science, or through science and technology centres. In relation to health messages in the media, Goldberg (1992) concluded that "short, unequivocal, positive messages targeted on single behaviours are effective, and that the natural temptation to complicate the advice ... should be resisted" (p. 76). This advice may reduce health messages to "mainly amoral, unconnected, often unreasoned assertions" (Burnham, 1987, p. 84), and further reinforce the image of many experts of an 'ignorant' public.

Irwin (1994), in a review of Layton et al. (1993), noted that experts often have an "insensitivity" and "scientific unawareness" of public need; indeed adults' knowledge is often dismissed and reduced to the status of "anecdotal" (p. 177). He makes an interesting observation in relation to the mass media:

> coverage in the mass media seemed peripheral to the heavily-contextualised needs of citizen groups ... the mass media seem apart from the kind of active 'sense-making' process ... All this is in contrast to the deficit model which ... typically stresses the mass media as a key mode of dissemination (p. 178).

The futility of assuming students in school science classes have 'blank minds' onto which we write our science messages has been well established by science education research of the past two decades. Similarly, it is time to reconceptualise our models of adult science education; in particular, Lave (1988) has urged "a rethinking of the nature of direct experience" (p. 182), a sentiment which is especially pertinent to human nutrition.

The adults in our study were all volunteers, and therefore we can generalise only with caution. Nevertheless, our study has demonstrated that simple nutrition messages are not received in the way the sender intended; there are also suggestions from many of the interviewees' comments that they are not acted on in the ways intended by the 'experts'. The area of adult scientific and technological literacy deserves more attention than has been the case till now. Our study suggests strongly that the 'cognitive deficit' model is not helpful; indeed, it may be counterproductive. If adults are to be helped in their everyday nutrition practices, we need better ways to conceptualise 'everyday practice' in this and other areas of human activity.

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A CONSTRUCTIVIST APPROACH TO SECONDARY SCHOOL SCIENCE EXPERIMENTS

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ABSTRACT

The focus of this study was on the investigation of a laboratory instructional program on electricity designed for conceptual development using constructivist principles for conceptual change. This approach was compared with a traditional laboratory approach in a quasi-experimental design. The sample was 247 grade 10 students (boys) in a large non-government urban school. Covariance analysis with the corresponding pretest as covariate showed statistically and educationally significant gains for the experimental group on cognitive but not attitudinal outcomes when compared to the traditional group. Student and teacher interview data provide some evidence for the success of the experimental approach.

INTRODUCTION

Laboratory based instruction is a unique feature of science education that has the potential to significantly enhance science learning. However, while there has been a considerable amount of research into the effectiveness of laboratory based instruction in recent decades, there remains concern that this potential has not been demonstrated and further research is required to develop instructional approaches to enable the laboratory to be a more effective element of science instruction (Friedler & Tamir, 1990; Hodson, 1988; Hofstein & Lunetta, 1982).

Research on the goals of laboratory work work that canvassed the views of school teachers (Henry, 1975), school students (Denny & Chennel, 1986), and the tertiary level (Boud, Dunn, Kennedy & Thorley, 1980; Hegarty-Hazel, 1986) has reached a broad consensus on the various aims of laboratory work. These goals include the development of: manipulative skills, although Woolnough (1989) cautions that the development of such skills should be to facilitate other goals rather than be an end in itself; scientific process thinking skills which includes the "doing science" of Hodson (1992) and the "problem solving scientist "of Woolnough and Allsop (1985); and the development of positive attitudes to science (Gardner & Gauld, 1990).

An additional aim for laboratory work which is of particular significance for this study is the development of conceptual understanding (Van den Berg & Giddings, 1992; Gunstone & Champagne, 1990). Reviews of the outcomes for laboratory work have shown that it is not associated with increased learning of science concepts when compared to other methods of science instruction (Bates, 1978; Bredderman, 1985; Tobin & Gallagher, 1987). However, Hodson (1992) emphasises that:

> Laboratory work in school should more often be used to assist the exploration, manipulation and development of concepts ... It is the exploration of ideas that constitutes the learning process ... (p. 67)

Tobin (1990) also argues that the laboratory should be a place for the development of understanding and provides some direction as to the kinds of student experiences necessary to achieve this end:

> Theory and research suggest that meaningful learning is possible in laboratory activities if all students are provided with opportunities to manipulate equipment and materials while working co-operatively with peers .... A crucial ingredient .... is to provide for each student opportunities to reflect on findings, clarify understandings and misunderstandings with peers, and consult a range of resources ... (p. 414).

An important feature of designing laboratory instructional programs should be to focus on a particular aim and to match the strategies and assessment to that focus (van den Berg & Giddings, 1992). The purpose of this study was to investigate a laboratory based instructional program specifically designed from a constructivist perspective to enhance cognitive learning and to compare the resulting cognitive and attitudinal changes with a traditional, laboratory-based instructional program.

RESEARCH DESIGN AND METHODS

Design

A quasi-experimental approach was used as it was required to use intact classes for the research. The sample consisted of 247 grade 10 boys in 10 classes studying physics in an inner suburban private boys school. Five classes were used as the control groups (N=119) using traditional verification laboratory work and five classes were used as the experimental groups (N=128). Some of the teachers taught more than one of these classes. Therefore, classes were assigned to control or experimental group according to whether the teacher expressed a commitment to a particular approach. A Non Equivalent Control Group design was used as shown in Fig. 1 (Campbell & Stanley, 1963).

Experimental	S_1A_1	X	S_2A_2
Control	S_1A_1	Y	S_2A_2

S_1: Science Concepts pretest
S_2: Science Concepts posttest
A_1: Attitude pretest
X : Experimental treatment
Y : Control treatment
A_2: Attitude posttest

Fig. 1 Research Design

The instructional program for the control group used typical verification laboratory work which involved following a set procedure, recording observations and drawing conclusions that verified previously discussed concepts. The design for the experimental program drew on the literature of conceptual development from a constructivist perspective. Five major features guided the design of the instructional program for the experimental group.

Feature one. Students' own ideas were elicited.

If students' prior knowledge was taken into account, then the probability of meaningful learning was higher (Heller & Findley, 1992; Shuell, 1987). Eliciting everyday experiences, making predictions about a situation or designing an activity were avenues that encouraged the students to use their prior knowledge.

Feature two. Students' own ideas clarified/challenged.

The practical activity tested the viability of the students' present concepts (Cosgrove, Osborne & Carr, 1985). Using the literature on known common alternate conceptions of electricity (Duit, Jung & von Rhoneck, 1985; Osborne & Freyberg, 1985), laboratory activities were designed to challenge the typical non-scientific views held by students about this concept (Closset, 1985; Cosgrove et al., 1985; von Rhoneck, 1985).

Feature three. Application activities planned.
The purpose of using multiple application activities was to reinforce previous activities and observations and to demonstrate the fruitfulness and plausibility of the revised way of viewing the concept (Closset 1985; Posner, Strike, Hewson, & Gertzog, 1982; Saunders, 1992). Application activities linked previous activities with the new ideas being investigated. The more links that were made between different ideas, the more fruitful was the information processing (Bjorklund & Frankel, 1989; Johnstone & Letton, 1991; LeFrancois, 1988).

Feature four. Real life situations used.
The use of everyday applications made the activities more relevant to the students and therefore provided some motivation to investigate further. Much of the students prior knowledge had been acquired through everyday life and therefore by using real life situations, the alternative views held by students on such phenomena were tested for their viability (Hartel, 1985; Shuell, 1987; Watson & Konicek, 1990).

Feature five. Time and space for student reflection and social interaction.
Students needed to be encouraged to express their views in some physical way, for example, by talking or by writing (Psillos, Koumaras, & Valassiades, 1987). These processes assisted in the clarification of the students own ideas and enabled them to test the viability of their ideas with their peers. The process of negotiating and reaching a consensus in collaborating groups not only heightened the level of discussion, but lead to students being cognitively active and hence facilitated positive student attitudes and achievement (Cosgrove et al., 1985; Roychoudury & Roth, 1992; Stanbridge, 1990; Tobin, 1990).

Four teachers in addition to those involved in teaching the experimental and control groups rated each of the written instructional programs on the extent to which the above features were included in each program. Fig. 2 shows the mean ratings of the teachers on the design criteria. Further, an additional two teachers observed the classrooms in action to verify that the programs were operationalised consistent with their intended focus. At the conclusion of the instructional programs, 10 students and the three teachers in the experimental groups were interviewed to provide a qualitative description of the implementation of this program.

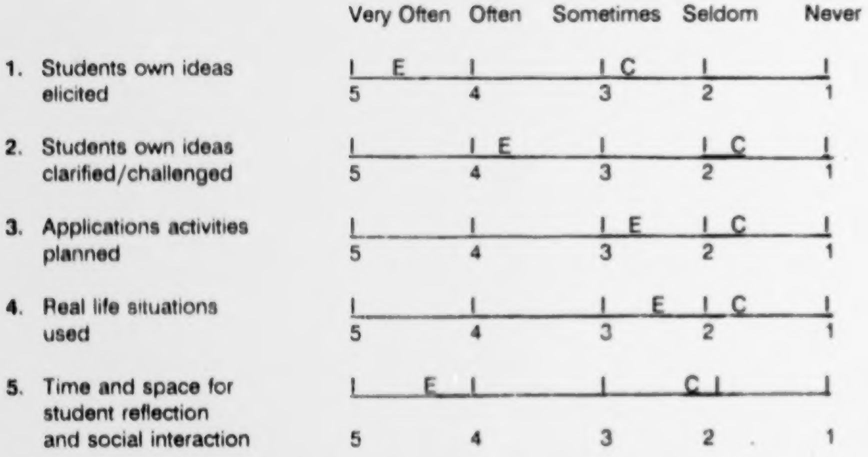

Fig. 2. Mean ratings for instructional programs on design criteria.
(E = experimental program; C= control program)

Teachers involved with the experimental groups underwent inservice education sessions to acquaint them with the aims and design features of the experimental approach, key features of a constructivist view of learning, some implications for teaching from this perspective which were adapted from CLIS Interactive Teaching in Science (Johnston, 1990), common alternative frameworks relating to electricity (Duit et al., 1985), and the writing of journals.

Test Instruments

Attitude Survey. Likert scales from an existing attitude survey (McRobbie, Fraser & Giddings, 1991) were selected for this study. The three scales selected as relevant to this study related to students valuing laboratory work as a learning experience, group work and the experimental attitudes of a good safe experimenter. A factor analysis confirmed the previous factor structure for these scales. Table 1 shows a sample item, the number of items and the Cronbach Alpha for each of these scales. The pre- and post-test questions were identical.

TABLE 1
SAMPLE ITEMS, NUMBER OF ITEMS AND CRONBACH ALPHA RELIABILITIES FOR EACH ATTITUDE SCALE.

Scale name	Sample item	No. of items	Cronbach alpha
Values laboratory	I find it more meaningful to learn concepts by doing experiments in the laboratory.	8	0.83
Values group Work	In group laboratory investigations, I find the ideas of other students to be very helpful.	10	0.86
Good safe experimenter	In physics experiments, I report unexpected results as well as expected ones.	10	0.82

Pre- and post-tests on science concepts. These instruments each consisted of 25 multiple choice questions (some different questions) which were predominantly conceptual understanding in nature and which related to (i) the need for a closed circuit, (ii) models of electric current in simple circuits, (iii) clarification of the terms *electricity, current, voltage,* and *energy* and (iv) the use of series and parallel circuits. The pretest used pictorial diagrams only whereas the post-test used circuit symbols for some questions. The validity of the items as relevant to the instructional programs was independently attested to by four experienced science teachers. The Cronbach alpha reliability for the posttest was 0.79.

RESULTS AND DISCUSSION

The results of this study are presented and discussed in three ways: as statistical analysis of the null hypotheses for comparing outcomes of the experimental and control groups, as extracts from student interviews and as extracts of teacher and observer interviews. The statistical evidence and testing of the null hypotheses will be presented first.

Hypothesis testing

Hypothesis 1. There is no significant difference in conceptual development between the group using conceptual development experiments and the control group using traditional format on the post-test science concept test with pretest knowledge as the covariate.

TABLE 2
PRETEST AND POSTTEST MEANS AND STANDARD DEVIATIONS FOR EXPERIMENTAL AND CONTROL GROUPS ON SCIENCE CONCEPT TESTS

Group	Pre-test		Post-test	
	Mean	St.Dev.	Mean	St.Dev.
Control	10.49	2.42	12.02	3.75
Experimental	9.82	2.49	14.29	4.83

Table 2 reports the means and standard deviations for the experimental and control groups on the pre- and post of the science concept tests. Analysis of covariance on the difference on the posttest means showed this difference to be statistically significant ($p<.05$, df=1,244) leading to the rejection of null hypothesis 1. Further, this difference in mean scores between the experimental and control groups (corrected for covariate) was considered educationally significant also as the effect size was 0.61 (pooled mean 13.12; standard deviation= 4.44) favouring the experimental group. This result suggests that the application of the design features derived from a constructivist perspective on conceptual change applied to practical activities results in enhanced cognitive learning and as such should be given more prominence in the design of practical activities with the aim of conceptual development.

Hypothesis 2. There is no significant difference in laboratory attitudes between the group using conceptual development experiments and the control group using traditional laboratory activities on the attitude survey scales using the corresponding pretest as a covariate.

An analysis of covariance on the difference between the control and experimental groups on the posttest means on each attitude scale showed there were no statistically significant differences. One possible explanation for this result may lie in the fact that both instructional programs were strongly activity based and as seen by the mean scores on each scale, were already quite positive. A further explanation may lie in the relatively short time span of this study (6 weeeks). Although the cognitive difference was evident in this time frame, a longer time may be required to bring about attitude changes.

Student interviews

Five students from each class in the experimental group were interviewed after the completion of the program. They were first asked for their general impressions of the instructional program and then more directly about the laboratory experiments if no comment had been made on them. The following five assertions have been drawn from these interviews. Sample student comments are given for each assertion.

Assertion One: The experimental work was a learning experience.
Students were supportive of the assertion that the experimental group instructional program assisted their learning.

> Now I know a lot more, mostly because we did the practicals that helped us understand.
>
> Practical work .... a lot more fun .... you could see everything happening and you could connect everything up yourself .... You also understand why it works, you just don't get told why it works, you actually understand it and see what happens.

Assertion Two: Students enjoy and learn more when doing their own experiments.
Students in the experimental group perceived value in testing their ideas by designing their own experiments to test the viablity of those ideas.

> We were able to experiment more .... try different things like make different circuits of our own ... get different answers .... put meters in and tells you everything about what's going on in the circuit ...
>
> Our experiments helped us to understand.
>
> ... doing experiments of your own they became interesting and you think for yourself .... go on and do other stuff ... learn by mistakes and trying again.

Assertion Three: Writing down thoughts (predictions, observations, explanations) assisted the understanding process.
By expressing their ideas on paper the students found they were able to clarify their views which assisted their understanding.

> You needed the writing because we were guessing and it showed what you know already and then what you find out.
>
> The writing got your thoughts about the experiment before and after to really find out what was happening .... it helped in the understanding about the actual series (of experiments).

Assertion Four: Working in groups created an environment rich with ideas and cognitive activity.
Students found the interaction of the various views expressed by the group members enhanced the learning process.

> .... other ideas, see how things might work .... achieved a lot more than if we worked separately.
>
> Some boys could explain to you and you could explain to others.
>
> You could sometimes argue what you thought was right or what you thought was wrong.

Assertion Five: Group work encourages inquiry and experimentation.
Working in groups enabled more ideas to be put forward to guide experimentation.

> We arrived at consensus by comparing results, finding information in other books and designing our own experiments.
>
> .... get more input to try different things, experiment on different things. It helps you get an answer.

Assertion one provides support for both the use of an experimental approach generally and for the approach in the experimental group as a source for learning. Assertions two to five give some support for the design features of the experimental treatment and indicate possible reasons for the statistically and educationally significant difference between the groups. In each of these assertions the comments show that the features of the experimental instructional program were reported as significant factors in assisting the students in their learning.

Teacher interviews

Teachers of the experimental group and observers referring to that group commented on the students' high involvement in cognitive activity such as predicting, comparing, explaining, negotiating, reflecting, clarifying and designing experimental activities. Following are some extracts from the interviews with the teachers and the observers.

> Teacher A: Last year's kids thought work we did with circuits seemed a bit low level. There was none of that comment this year. The emphasis being of course that they were thinking about the concepts in more depth. We were exposing them to more cognitive processing. They seemed to be enjoying the fact that they had to really think about things which in the past they really weren't doing to a great degree.
>
> Teacher B: Compared with the same kids in other classes/years, they were very much higher on task for the exercises.
>
> Observer A: All the kids were doing something and actively doing it as they were supposed to. This was different to the control group and different to what happens in most other classes.

However, while the teachers in the experimental program were enthusiastic about the conceptual test score results and the group dynamics, they did express some concerns on group dynamics, written expression and time pressures. Firstly, it was felt that the students needed some guidelines about how to work in small groups. One suggestion was to provide some introductory statements in the front of the student journal along with sample stem questions that could help the discussion process. Secondly, the boys found it difficult or were reluctant to express their views on paper. Journaling was therefore limited in the initial stages. As the unit progressed the writing and extent of journaling did improve suggesting that with further experience and the provision of some guidelines, this aspect could be improved. The third concern mentioned was about the time necessary to complete the programs. The control group felt had no difficulty in completing their instructional program in the time allocated. Although the time allocated to each instructional program was the same, the experimental group would have preferred more time to complete their instructional program. While it is probable that the experimental group may work more efficiently with more experience with that type of program, the additional time required would be justified on the educationally significant difference in conceptual learning resulting from the experimental program.

CONCLUSION

This study showed that where school science laboratory activities were designed from a constructivist perspective for conceptual change there was an educationally and statistically significant increase in learning when compared to an instructional program based on the more traditional laboratory activities. However, no statistically significant differences were found for a comparison of attitudes between the two instructional programs. This study suggests that the science laboratory can be a more effective mode of learning if the experimental activities are designed from a constructivist perspective on conceptual change, and provides direction on the kinds of features that should be included in future laboratory instructional programs designed to enhance learning.

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"I WANT TO FIND OUT HOW THE SUN WORKS!" CHILDREN'S SOCIODRAMATIC PLAY AND ITS POTENTIAL ROLE IN THE EARLY LEARNING OF PHYSICAL SCIENCE

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ABSTRACT

Our interest in a potential place for sociodramatic play in the early learning of physical science was activated while interviewing two six year old girls after the classroom phase of our research study had ended. During spontaneous play, these girls initiated inquiry into questions that had remained unanswered for them at the end of the teaching about Light.

INTRODUCTION

In the process of interviewing children from three classes who were participating in a study into early learning of physical science at a primary school, Gilda was talking to Sarah and Stephie, two six-year-olds, about shadows they were making using torches. Unexpectedly, Stephie asked Sarah, "Sarah, do you want to do a play?" and then turning to Gilda, Stephie requested, "Can we do the play now?" Gilda agreed, leaving her video on. As the play unfolded, the children pretended to be sisters going to the beach. There, Stephie went for a swim, "Splash!" Sarah, putting on sun glasses the girls had found earlier in the room, (the school's sick bay) settled herself in a (deck) chair on the sand area, stretching back with a relaxed smile on her face, enjoyed warm sunshine. Looking at the light from a torch they had arranged (as the sun) to shine on their beach from one side of the room, Sarah suddenly proclaimed: "Hey, I've found something out. But I'm not quite sure how it works though". She offered the sun glasses to Stephie, urging her, "Put these sun glasses on and look at the sun." Sarah continued "I can even see it now." Then moving to one side on her chair, looking seriously at the sun, she breathed with feeling: "Wow!" Stephie put on the glasses, stated that she saw a rainbow and reminded her fellow player: "You haven't even had a swim." Sarah rejoined in a sing-song, slightly petulant play-voice: "I don't want one." "Let's go home," replied Stephie, but Sarah, wishing to prolong the game, continued, "It's so warm in the sun." "Let's go home," Stephie repeated. Then Sarah jumped up and announced firmly, "I want to find out how the sun works." Suddenly aware that this was close to the subject matter of their recently completed science unit, Light, Gilda listened closely.

Children, like these two girls, want to understand their world. What part might their play take in this urge? During play, children, in control of events and interactions, are motivated and self-directed as they manipulate objects and situations with a high level of concentration, engagement and enthusiasm. With these attributes, does play, and especially sociodramatic play, (a dramatic pretend play, involving two or more players (Smilansky, 1990)), offer scope as a learning environment in early childhood science classes at primary school?

PLAY AND LEARNING SCIENCE

Research on play in the context of science education is sparse if our ERIC data base search represents the actual position. In practice, although some teachers have appropriate equipment within their classrooms for play, sociodramatic play is not a conscious part of their curriculum (Smilansky, 1990). The role of play in learning is not disputed (Bruner, 1976; Vygotsky, 1933/1976; Wassermann, 1990). Little enough is known about how people learn, but there is no doubt that young people are especially adept at it. Learning can be compelling: Papert (1980) describes the intensity of his very early relationship with learning about gears where both love of learning and cognitive development were woven into the relationship. It is this kind of natural learning which we would like to incorporate into early primary science education.

Natural learning, in Plotkin's (1994) analysis of the ways that gene-pools, brains, immune systems and cultures learn, is generative. The neuroscientific view of the brain is that it is not a computer following pre-existing instructions. Neuroscience has a Darwinian theory which posits that "both perceptual and conceptual categorization arise as a result of selection upon pre-existing variance in structure and function of the nervous system" (Edelman, 1993, p. 115). Within a human brain, there are billions of possible connections between nerve cells. Interaction with the environment selects those connections which best suit the organism's value system. Those valued connections which are used and which are useful, are strengthened and are likely to fire again. This has two implications for early learning of science at school: first that some pathways are strongly formed already through natural learning; second, that in our view, certain early school science learning experiences (e.g. Segal & Cosgrove, 1993) can help to select and strengthen those connections which promote empowerment of children by arousing their curiosity and stimulating their initiative for further learning along paths which interest them. If the early learning of physical science is successful then many of the problems of later learning (Freyberg & Osborne, 1985) may be offset.

We see play, a form of natural symbolic and exploratory learning, as one bridge to forging an experiential, inquiry based and imaginative science education for the young.

Here we first describe the circumstances which led to the play vignette presented in our introduction. Then we extend our description of the play, adding two layers of interpretive comment: first, upon its value in meeting the girls' learning urges; second, upon the access it provides to the girls' interpretations of inquiry in science, the pedagogy underpinning their recently completed science unit. We end with suggestions for incorporating play into science lessons in early primary school.

THE STUDY

Stephie and Sarah were Year 1 students in a Year 1/2 Composite class (N_1 = 18; N_2 = 12) in a primary school in a middle class area of a large city. Through the school's links with the University (in several projects), Sarah and Stephie's teacher, together with two other teachers, had volunteered to assist Gilda in her research into children's ideas about light, by first collaboratively writing a unit on Light, then having Gilda as participant observer in their classrooms while they taught the unit. Gilda's interest was in researching the children's learning during and after classroom teaching and in collaborating with the teachers in evaluating the unit. Part of the design involved Gilda visiting their classrooms at least once a week, from the beginning of the school year in February, to become acquainted with the children and with classroom procedures.

Mark had introduced the teachers, during a year-long, whole school inservice program (Schaverien & Cosgrove, 1994) to a view of learning which encouraged children to generate questions about events that interested them and to explore ways of gaining answers (Biddulph & Osborne, 1984; Faire & Cosgrove, 1988). The value of this approach is in allowing children to generate their own questions, and on sharing publicly expressed questions, to articulate ideas and then follow their interests in exploring and inquiring into answers to questions selected from those they and others asked.

During writing in May and June, (eight sessions: 22 hours), the three teachers and Gilda clarified their understanding of some basic properties of light (propagation, formation of shadows and reflection), discussed ideas children may hold and devised learning sequences with an emphasis on inquiry. The teachers taught the unit from mid June to mid September, (11 sessions, each 1-2 hours for Year 1/2) with a mid unit break occasioned by school holidays and Gilda's university commitments. During the mid unit break, Gilda interviewed about half the cohort to gain further insights into children's views about their learning. The children were found to be highly engaged by many conversations in which they generated ideas, by experiments in which they tested them and they keenly recorded ideas and drawings in personal Light Logs.

Gilda talked to all of the children, in pairs, in November, recording (by audio and video) the conversations and actions. The play described in this paper occurred then. In this evaluative stage, some specific research questions (questions 1 and 2 below) and a more general speculative question (question 3 below) emerged, concerning the meaning of the play for early childhood science education. Research questions which concern the whole project are not discussed here.

Questions emerging from the play episode

1 How might the play have benefited the girls' learning (not just of science)?
2 Can the play episode be traced back to their work on the light unit and thus help evaluate the children's experiences and understandings developed during the unit?
3 Could this play episode be meaningful in a wider sense, suggestive of a science curriculum of which a part can be framed to offer children opportunities to engage in sociodrama and, perhaps, other forms of play as well?

THE PLAY

Our interpretation of the play dialogue is based upon Gilda's knowledge of the players, the insights added by their teacher, our discussions with each other and other researchers to whom we showed the video and some theories of play explicated in play literature. We include some dialogue and description of the children's actions to invite readers to make additional interpretations as they wish.

Early stages of the play

As the originator of the idea of the play Stephie assumed a director's role. She decided that the action was to take place at a beach and cast Sarah, holding the torch, as the sun. Abruptly, Stephie changed her mind, re-defined roles and announced they were to be sisters.

Stephie: My name's Nancy.
Sarah: I'm Kara.
Stephie: Kara [*laughs*].
Sarah: Hey Nancy, remember Mum said we were going to the beach today?
Stephie: Yeah, let's get dressed.

The girls' choice of character names is not arbitrary. Nancy and Kara are Year 2 girls in their composite class who are close friends and who always choose to work with each other. When told about the play names, their class teacher said she was not surprised as Nancy and Kara are role models for the Year 1 children. For Sarah, who returned the name Kara to Stephie's Nancy, the real Kara's and Nancy's friendship may have determined her response; for Stephie, a child with social difficulties, Sarah's response could have had a deeper meaning: her suggestion of closeness of sisters was being matched by her play partner's choice of friendship name.

Continuing the play story

After driving to the beach and 'applying' suntan cream (from a glue bottle), Stephie decided to swim and made a running dive into the water. Sarah settled back, with the sun glasses, legs stretched out, looking exactly like someone sitting on a deck chair at the beach, initiated the inquiry sequence we have already reported in our introduction:

Stephie: "Let's go home."

Sarah: [*jumping up and announcing firmly*] "I want to find out how the sun works".

This was not the first time that day that Sarah had proclaimed an interest in the sun. In a short conversation with the girls as they came to the interview room, Stephie asked Gilda, by way of starting their conversation, "What is light?" to which Sarah added that she also had a question, "What is the sun made of?"

In the play, therefore, Sarah's firm rejection of Stephie's suggestion to go home signals again her curiosity about the sun and a determination to pursue her inquiry, which links to our pedagogical approach in the Light Unit. Her announcement that she wanted to find out how the sun works, also heralded a change in the power relationship between the girls with a transfer of responsibility to Sarah to decide the future path of the play.

Inquiry in play and science education

Stephie, unsure of the new direction, took up Sarah's demand for inquiry by stating "Let's do an experiment." Turning to Gilda, she explained her new interpretation of their actions, "Now it's starting as an experiment" and requested some water and crayons (presumably to repeat an activity she had carried out in class). That Stephie should automatically assume that a way of finding out is through experimentation is linked to the inquiry emphasis of Light Unit. Direction of the inquiry, though, remained in Sarah's hands.

Inquiry about the sun

Sarah, wearing the sun glasses, began her inquiry:

Sarah How come it's so high up? What's it made out of? [and in quick succession] Why is it so far up? How can we get up there?

Stephie entered the Sarah's scenario without further prompting.

Stephie Let's try and find out [*encouragingly*].

Sarah We'll never get up there [*despairingly*].

Stephie In a rocket ship? [*brightly*].

Sarah Give it a break! We'll never build one of those things. [Slight pause.]

Stephie We could...

Sarah I know!

Stephie O.K. Are we going to jump up there? [*standing up on the bed, seemingly ready for action*].

Sarah Definitely not. We are not even going to go up there, we are just going to look.

Stephie standing on the bed, with her hands on her hips as Sarah replied, suddenly jumped down and ran toward the book shelves, calling:

Stephie You look and I'll see if I can find anything about it.

Walking up and down and holding the sun glasses on, Sarah eyed the sun, while Stephie selected a fiction book from the shelf. Meeting up with Sarah, Stephie claimed to have found out something: the sun is made of coal.

Sarah But does it run on coal?

Stephie I don't know, actually.

The girls' experiences of generating questions and ideas for inspection and testing them are on view here. Stephie, using information supposedly obtained from the book, put forward for comment, her contention that the sun is made of coal. Sarah paid close attention to Stephie's idea, considering its implications, just as they had been encouraged to do in class. Her question complimented Stephie by implying that her idea was worthy of further consideration. Simultaneously the question allowed Stephie time to acknowledge the tentative nature of her claim in a dignified way, an important skill in theory-building in science and, significantly for Stephie, in social interaction. Thus Sarah, adeptly, accomplished scientific and social goals by not rejecting Stephie's view explicitly or implicitly, by offering her own opinion too soon.

Adopting Stephie's idea of using books as a source of knowledge, Sarah also examined books on the shelf, continuing their sister link by using the name Nancy, and signalling her continuance of the play.

Sarah: I know something about it, come over here Nancy.

Reading from her Light Log, (which Gilda had in the room to discuss with the children as part of her procedures for triangulation of data,) she improvised:

Sarah: Oh, look, the closer you get to something, when you have a torch, **or maybe even a sun**, the [light from the] bulb gets darker and smaller.

Stephie, joining in, read from the same Light Log:

Stephie: The further away you get, the bigger it gets and the lighter it gets. Let's try it.

(Temporarily diverted by checking the observations Sarah had recorded earlier in the year, they examined how the circle of light on the floor varied in brightness and size as the torch is moved away from the floor. Gilda had had earlier discussions in class with Sarah about the experiment described here. Sarah uses the term "darker" to mean more intense and "lighter" to mean less intense. Stephie's statement indicates that she too, uses "lighter" to mean less intense in this context.)

Stephie: Look, it works, it's true.

Sarah re-directed the investigation:

Sarah: What are we going to do about the sun? We've got to find out how it works.

Stephie: And what it does.

The investigation in this section again directly provides access to the sense that they made of their Light Unit experiences, where they were presented with many opportunities for generating and testing ideas. On this occasion, Stephie, reading a claim in Sarah's Light Log, suggests an empirical test to which Sarah does not object, even though she is still concerned to continue her original line of inquiry about the sun. This is perhaps another indication of Sarah's interpersonal skills in allowing Stephie to direct part of their action, and may also show her belief in the worth of reconsidering ideas, an attribute she had displayed on other occasions during the year.

Reading directly from their Light Logs was becoming a little frustrating, as during their previous writing about their science activities, they had recorded nothing about how the sun works. Sarah partly solved this problem in the conversation above, where she inserted "or maybe even a sun" into her sentence about the behaviour of the torch. In the following passage, she took this solution one step further, completely eliminating the problem, by pretending to read something from her Light Log, **which she made up**.

Sarah: I'll read it, I'll read it in this book. **The sun is made out of fire.** *[At this point, Stephie looked up at Gilda and gave her a huge grin of seeming enjoyment of the whole situation, perhaps enhanced by Sarah's pretence of reading.]*

A little later

Sarah: Here's an experiment. Have a look at the sun, put some sunglasses on and see what you can see. [*She was pretending to read this out of her Light Log too.*]
Stephie: We've done that. I'll show you something.

Illustrated here again, are complexities involved in communication in play, their elegance and sophistication, as a reminder of young children's well developed natural learning abilities. Sarah, now, through the device of pretending to read the information, offers an alternative theory, that the sun is made of fire and a means of testing that idea by inspection through the sunglasses. By incorporating her alternative idea as part of the play, Sarah did not challenge or reject Stephie's notion that the sun is made of coal, even though Stephie herself acknowledged that she was unsure of it. Just as in class, more than one theory was allowed to stand at a time, awaiting further evidence to distinguish between them.

Ending the play

Sarah: We've got to go home soon. Mum will be worried. [*She looked at Stephie and smiled meaningfully.*])
Stephie: Oh [*disappointed*].
Sarah: Just one more thing. Then we'll go home and look it up.
Stephie: Now here it says, here it says, and 'The sun sometimes can work by coal', but we don't know that yet.
Sarah: Well we could try something when we get home, look in one of our books.
Stephie: We've got coal at home, we can try and make it. Let's go and see, let's go home.
Sarah: OK.
Sarah: We're home.
Stephie: No, we just run in the door. [*The final action of the director.*]

This last scene is almost a summary of the children's feeling for the nature of scientific inquiry, as they had experienced it during the Light Unit. Stephie acknowledges the tentative state of her knowledge, they both remain open to the possibility of new ideas and they join together to re-iterate three important ways of finding out -by direct experimentation, by collaboratively exploring ideas and by looking up books. The scene also encapsulates the duality of play communication as they pay attention to each other's mood signals while building them into the story: Stephie recognises that 'going home' is Sarah's code for ending play; Sarah recognises, in turn, that Stephie is still enjoying the play, and holds out the possibility of further action at home.

As they enacted arriving home, Stephie seemed to want to continue, but Gilda taking her cue from Sarah's play suggestion of returning home and other non verbal language carrying the same message, told them that they needed to stop now, as she had more children to talk to. They happily made plans for continuing tomorrow in the playground. Poignantly, each seemed to state what was important and significant for them, in their closing statements.

Sarah: Yes, we'll play it tomorrow outside and we'll try and find [out] things.
Stephie: Just together?

DISCUSSION

There are three insights directing our view of this play episode. First, it meets children's learning urges: their demeanour during play and final comments lead us to assume that they enjoyed playing, while our analysis indicates that reviewing their Light Unit learning experiences in this natural way could have assisted their development cognitively, socially and emotionally. Second, as a way of evaluating learning, it meets some of our needs as teachers and researchers: watching the play allows us access to some of the meaning that Sarah and Stephie have constructed from participating in the Light Unit. Third, as a tool, it bridges natural learning and science education in early primary school: this episode suggests a possible pedagogical strategy for future science learning in early childhood education.

A view of the play as meeting children's needs

Stephie gradually made progress throughout the year in managing her interactions with other children, according to her class teacher. Gilda also noticed this change. It was probably advantageous for Stephie to initiate play in a situation she regarded as safe, as it allowed her to consolidate and practise her emerging social skills with a child who had previously been accepting of her. With no sister, it was Stephie who suggested their play sister relationship. There was a learning benefit too. Although she was an advanced reader, Stephie had shown a lack of interest in formulating her own questions during our unit and at times, had indicated a lack of confidence in having ideas. Taking part in enacting an inquiry may have assisted Stephie in gaining a feeling for the processes involved, helped by her interactions with Sarah, a proficient inquirer.

Sarah, as their story unfolded, turned the play towards her current interest in gaining an answer to her earlier question about the sun. Incorporating this question into the drama allowed her to play, literally and figuratively, with a question she found fascinating.

An evaluative view of the play

In this play episode, Sarah and Stephie displayed, practised and perhaps internalised many of the attitudes that we value as science educators. They identified a genuine and meaningful question of their own, brainstormed various ways in which they could gain information to help answer the question, (including direct experimentation and indirect consultation of references), eliminated some suggestions which seemed too extreme, and concentrated their attentions on others, sensitive, mostly, to each other's social and emotional values. In considering some possibilities, they had open minds as they resolved to find out more information in places not immediately accessible to them. We infer that Sarah and Stephie know some of the authentic ways in which people, including scientists, go about their inquiries.

The play therefore not only makes apparent the girls' knowledge of some learning processes in which they have engaged, but it suggests that the freedom to formulate and investigate their own questions during our unit on Light, stimulated their re-engagement with these processes within their play setting.

Playing and learning

In retrospect, playing seems almost like an imperative for Stephie and Sarah. Using natural ways of learning, the children were able to reflect upon, re-examine and extend their classroom experiences - they did not need a teacher to show them how to do this. Nevertheless, the context (including past experiences, presence of resources and free-ranging conversational interview with a trusted adult) was facilitating. We feel that our insights, together with information from the literature, can assist teachers of early childhood classes to make opportunities for sociodramatic play available within science education.

A view of play as a pedagogical strategy for future science learning

Function of play. Researchers and play theorists view play and its functions from varying paradigms (Rubin, 1982; Sutton-Smith, 1979): as assisting learning by allowing children to develop symbolic representations of the world (Vygotsky, 1933/1976); as allowing children to practise in childhood, activities which will be needed for adult roles (Bruner, 1976); as aiding in the development of creativity and emotional growth (Singer & Singer, 1990).

Complexity of sociodramatic play. Stephie and Sarah's play demonstrates that the awareness on the part of a pretender of "a mental representation that is different from reality", and "a layering of the representation over the reality, such that they exist within the same space and time" (Lillard, 1993) is complex. Bateson (1955/1976) highlights the intricacies of the communication involved; he states that humans communicate on multiple levels of abstraction, where one series of levels of abstraction, called meta-linguistic, is the implicit and explicit meanings of the language of the discourse and another set of abstract meanings of the discourse, called meta-communicative, is the relationship between the speakers. Play can only occur if the participants correctly send and interpret meta-communicative signals carrying the message 'this is play'. These signals enable participants to distinguish between mood-signs, and messages which simulate mood signs (Bateson, 1955/1976). Young children accomplish these complexities effortlessly, as evidenced several times during this play.

Our experience with Stephie and Sarah's play suggests that some teachers may overlook the potential of this natural, sophisticated way, by which children can consolidate their learning in science.

Incorporating sociodrama into science. In order to provide opportunities for this kind of symbolic play as part of science education, teachers would need subtly to provide situations and props which are suggestive of science activities previously undertaken. By the very nature of symbolic play, teachers cannot be prescriptive, enforce structured scenarios on children, assume inappropriate roles, interrupt to teach rules, concepts or vocabulary (Jones & Reynolds, 1992), but they can actively participate, by joining in the drama if invited, by suggesting roles, by arranging partners, by extending children's conceptions of roles, by using vocabulary and concepts in the context of the play, by retaining a sense of dignity and by discussing some concepts later, in a sensitive, thoughtful fashion. Teachers will need to be highly observant, patient, alert to children's feelings about being observed while playing and most importantly, willing to pass control of the play to the children and not interrupt play (Jones & Reynolds, 1992). In addition to paying close attention, teachers can make notes or drawings about the play, so that later, through representing stories and images of their play to the children, (Jones & Reynolds, 1992), they can build a shared classroom culture around a theme, as proposed by Dewey (1938/1963).

CONCLUSION

This small study within our research into early learning of physical science helps in understanding the value of situational aspects of play and its relationship to science education in (and out of) primary school. Advantages for children, as part of their science education, include avenues for reflection, for development of ideas, and for social and emotional growth; an advantage for teachers is an opportunity to gain insight into children's thinking. Both aspects have been exemplified by this play episode.

As foreshadowed by our speculative third research question, we wonder whether teachers can incorporate opportunities for play within early childhood science education in the primary school and we have offered some suggestions, based upon play literature as to how teachers might manage this. This opens an avenue for further research.

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NARRATIVE IN THE SCIENCE CURRICULUM

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ABSTRACT

Internationally, science curricula make specific demands on students for the achievement of some level of scientific literacy. The details of what this means, and how it is to be achieved, have often been left for the teacher to elaborate. This paper argues that **narrative**, as a valued component of scientific literacy, offers a structure that allows scientific concepts to be (1) more easily integrated into other conceptual understandings, (2) more easily recalled, (3) more easily ordered and structured in the mind, and (4) an important component of the what it means to be a Self. The paper ends with practical suggestions for the use of narratives in the science classroom.

NARRATIVE

Narrative defined

What is narrative? Given the enormous literature that has arisen around this word and its place in human language and thought, a more appropriate question might be; what will narrative be taken to mean here? While it is tempting to apply the word **story** as a working definition of narrative, story itself is badly in need of more precision of definition, as well as conveying a hint of something immature and unable to deal with the rigorous analytical and descriptive needs of science. Narrative itself is subject to the same concerns of rigour and precision.

> It is already clear that narrative is a tremendously inefficient way of exploring the ways in which science interprets the world and positively distracts students from building up scientific understandings (Halliday & Martin, 1993, p.199)

Through the work of scholars of language (e.g. Martin, 1986) it has become clear that stories per se do not encompass or define what should be understood by the term narrative. For example, one of the earliest definitions of narrative was given by Prince as

> ...the representation of at least two real or fictive events or situations in a time sequence, neither of which presupposes or entails the other (Prince, 1982, p. 4).

For Prince, 'events' refer to the more active elements in a narrative, while 'situations' refer to the passive setting in which those events occur. One immediate advantage of this definition is its reminder that narratives can deal with real events as well as fiction.

Why two events? Less than two is felt to be a statement of fact or condition, which does not satisfy the minimal conditions of a narrative (e.g. "He went outside"). With two discourse units, the possibility of a plot begins (e.g. "He went outside. His car was missing"). Andrews (1992) has argued that most narratives constructed by children include at least three elements, allowing for the possibility of the familiar 'beginning, middle and end' structure of story (eg. "He went outside. His car was missing. His wife had left him").

Time sequence is an important and often discussed feature of narrative. It is only important to point out here that narratives need not be chronological, of course. A narrator is, given the constraints of the sort of narrative to be told, free to move from past to present to future. This control over the time frame of the narrative emphasises an important distinction between the events of the narrative (say, a laboratory procedure) and the way those events are represented in the narrative. This may allow narrative to address the reality of the scientific method, rather than conforming to the mythological presentation of scientific discoveries in the scientific paper or the textbook.

> The story goes something like this: science begins with observations, then by induction the investigator arrives at a hypothesis which is subject to experimental testing. When the hypothesis has been confirmed and linked with related hypothesis on the same subject, scientist formulate laws of nature. When laws of nature are collected and combined, scientific theories are produced (Factor & Kooser,1981, p. 87).

We are now, in the late 20th Century, in the middle of an intense revival of interest in narrative. For our purposes, it is enough to adopt a common sense interpretation of the varied and subtle definitions, and think of narrative as the telling of sequential events in a way that portrays a meaningful, coherent whole. It implies a teller, referred to from now on as a narrator, and a receiver, or narratee. It is familiar to us in the countless narratives we tell ourselves and others every day: how I lost and found the car keys; whom I met at the dentist; how will I organise my next seminar?; why did he look at me like that? Narratives are not bound by length, or time of telling, or skill of narrator.

Specific arguments for narrative

In what follows, four specific arguments for the usefulness of narrative in science education are presented. They are based on considerations of curriculum integration, pedagogy, the structuring of curriculum content in the mind, and on certain views of the self which give narrative a decisive if not essential role in determining, if not defining, who we are.

NARRATIVE IN SCIENCE EDUCATION

Curriculum integration

For the purposes of this paper, let us assume that the contents of the various science curricula (such as the South Australian Certificate of Education, or SACE) satisfy contemporary demands for student exposure to current cultural concepts as these impinge on, or are influenced by, science. It is argued here that what these curricula lack is a recognised integrating mechanism to bring about one of the key goals of scientific literacy: the anticipated and valued links between science content and the various curricula areas outside of science. Not surprisingly, I take the view that narrative can provide such a mechanism.

There have been many attempts to identify a skill, or theme, or process by which to braid into a single cable the separate strands of the curriculum. For example, 'critical thinking' or 'problem solving' have been seen as the adhesive force; 'Language Across the Curriculum' (Marland, 1977) represents another attempt, one closer in principle to what is argued for here. These approaches rightly try to find commonalities in the structures of the separate disciplines (i.e. all disciplines are based on conceptual thought embedded in language), or in a skill that is seen to be useful in the analysis and evaluation of them all (i.e., problem solving or critical thinking). If narrative is to fare any better than these other efforts at playing such an integrating role, it must display some clear advantages.

One powerful argument in favour of narrative, suggesting that it is one of the wired-in, essential representatives of human thought itself, will be examined later in this paper. Here, the weaker claim is made that narrative allows easier transfer of knowledge across disciplines. That is, if the student has placed discipline knowledge, gained through the hard-won (and still contested) methodologies of that discipline, into a narrative structure that is personal and clear (to them as narrators, and clear to the narratees), then **the narrative form itself** will place that knowledge in such multiple contexts that it is no longer compartmentalised, but integrated. Put another way, the narrative structure can be seen to be similar to a concept map, but one that explicitly links disparate understandings into a coherent whole (that of the narrative) and values those links (because they form and allow narrative to occur). Narrative is thus seen, not as a common element of all discipline knowledge, nor as a skill that should be applied to them all, but as an adhesive force, a binding force, that brings diversity into coherence.

Support for this view comes principally from researchers into the development of narrational skills in children, both developmentally and across cultures (e.g. Andrews, 1992). The interpretations of this research range from the conclusions statements of Fisher (1987) that:

> ...humans are essentially storytellers,...(and) all forms of human communication are most usefully interpreted and assessed from a narrational perspective....(The) human species is always pursuing a **narrative logic** (emphasis in the original, p. ix).

through to the weaker claim that the ability to write and read stories is natural but demands intentional development by schooling (Freedman, 1987; Andrews, 1992). There is a great deal of research that highlights the ways the unschooled child naturally recounts stories (e.g. Graves, 1982; Wilkinson, Barnsley, Hanna & Swan, 1980), along with literature in the area of literature and language education that documents the ways that children's narratives incorporate materials from the entire spectrum of their experiences (Bartlett, 1932; Freedman & Pringle, 1984).

Fisher (1987) claims that even "argument" pursues the narrative logic, and a simple example of this can be given here, with the use of an analogy with some of the current understandings of how structure arises in the world of the physical sciences. It appears that, for all the forces except gravity, the interchange between the particles that are held together by the force is mediated by a third 'exchange' particle which is transferred back and forwards between the two. This constant exchange is responsible for the attractive or repulsive forces experienced by matter.

This analogy explicitly suggests that narrative is playing the role of the exchange particle for human interactions. We are bound one to another by the narratives we share (and can share); the more narratives we have in common, the more tightly we are bound to the culture that contains such stories. If we increase the number of narratives we share, we increase our coherence between a wider range of cultural elements. Put in a specific context, to establish curricular coherence with science, students need to share in the stories about matter and energy and life that scientists tell each other. They can do so by reading the narratives directly in the research articles, of course, though this requires a degree of knowledge and experience with science that usually lies at the end of schooling. Or they can encounter such narratives through the work of the popularisers of science (in the analogy, they would be the originators of the exchange particles). Just as importantly, if not more so, students can also construct their own narratives in which science plays a natural, unforced, necessary role. It is in this second activity, as creators of narratives involving science, that the opportunity exists for them to use narrative to forge the links between disparate knowledge. Science concepts can take their place in the narrative alongside history (discipline or personal history), poetry, human relationships, political thinking, or whatever, simply because the narrative form is infinitely flexible and accommodating.

Narrative as a pedagogic tool

A second argument for the value of narrative in science education is based on the pedagogic value of narrative. In this view, narrative, by its very structure, places concepts in acceptable, easily assimilable and memorable form. Put simply, it suggests that what we encounter couched in narrative form, we remember. This view is argued for on at least two grounds.

First, the narrative format is one of great, if not universal, familiarity to all cultures.

> ...all forms of human communication need to be seen fundamentally as stories--symbolic interpretations of aspects of the world occurring in time and shaped by history, culture and character...(Fisher, 1987, p. xi)

Fisher refers to humankind as **Homo narrans**; similar perspectives can be found in the work of McCrone (1990) and Moffett (1968). If someone from our Western culture states "Once upon a time..." we all know what is to come. We remember such narratives because they are couched in a format with which we are all familiar. The way the narrative is sequenced (from beginning to end) appears to permit if not actually demand easy recall; one event immediately suggests its successor. This sequential structure is familiar in many more artificial mnemonics, or aids to memory, where objects to be remembered are chained in the right sequence into an artificial story; as the story unfolds, the to-be-recalled objects appear on demand. Narrative's links with memory have been explicitly studied in cognitive science (Cohen, Eysench & Le Voi, 1986; Aitkenhead & Slack, 1985); and in psychology over many years (Whorf, 1956; Finke, 1987; and more recently McCrone, 1990).

Second, sequence alone is not enough, of course. The narrative must not be so artificial that memorisation is purely by rote. For it to be put in the personal, meaningful form, the narrative must also be couched in the appropriate language of the narrator. For readers of such narratives, it is a question of the selection of narratives written by others which do this most successfully, with the ultimate aim of being able to read narratives as found in the mature discipline. For the writers of such narratives, it is a question of finding ways of becoming more and more competent at the production of narratives that more fully reflect the scientists' world views as well as maintaining personal connections to the knowledge. This has long been a concern of those responsible for the teaching of writing and reading as a developmental process; the appropriate match of language to audience. Marland (1977) was concerned with this sense of audience when he wrote

> Pupils (have) to manipulate their knowledge and their language to serve an audience other than themselves and their teacher, and...you only really understand ideas...when you can play with them...The development of writing abilities is partly conditional on the more general development of the writer out of egocentrism; but the general development may itself be aided by the practice of writing (p. 163).

In science classrooms, this partly translates into the demand that the narrative must be as true to actual science as possible (because the teacher and authorities in science are part of the audience) while still being the student's narrative; it must tell both the true story of matter and energy while fully representing the world of the narrator. If it does both, then it will be more fully present to the mind as an object of contemplation whenever desired.

Narrative and human experience

It has been argued (e.g. by Fisher, 1987) that narrative reflects the way the human mind orders experience. In this view, narrative is not simply one of a number of possible ways of encoding and reporting experience. Instead, we have the narrative structures we do because the mind is a narrative-making entity. According to Hardy (1975):

> Narrative...cannot be regarded simply as an aesthetic invention used by artists in order to control, manipulate, order and investigate the experiences of that life we tend to separate from art, but must be seen as a primary act of mind transferred from life. (p. 4)

Her evidence for this comes chiefly from an extension of traditional literary studies of narrative forms in fiction, and from the investigation of children's narrational development, as mentioned in the argument on pedagogy above. All cultures narrate, and all children with non-pathological biological and social capabilities narrate without the necessity for specific, formal instruction. Furthermore, whether in oral or literary cultures, all members can understand narration; the implication is that we are biologically adapted for the narrative way of organising experience: "Nature, not art, makes us all story-tellers."

This perspective implies that the structural features associated with narrative, such as temporal and spatial factors, sequence, event, tone, tempo, and so on are fundamental aspects of the human mind. A close examination of the processes of conscious thought would then reveal similar structures. What is missing from this scheme is the role of the unconscious mind in the development and generation of narrative: the creative and imaginative factors that make narrative so diverse and individual. As a purely speculative aside, there may be a connection with Chomsky's deep structures, a necessary underlying grammar, and the resulting large scale narratives.

If the view put forth here is correct, then the implications for science education become clear. For science knowledge as presented in schools to be ordered within the mind's framework, it should ideally, at least initially, be couched in a narrative form. This may be done either by the interpretive disciplines for the students through popular works, or by the students in their own efforts to narrate the science they have been presented with. By turning science knowledge into a narrative form, they are making it conform it to the way in which the mind necessarily orders all experience.

An exploration of this view into the discipline of science itself suggests other factors that may influence the way science is considered as a human activity. For example, it would follow that if the formal scientific genres, as expressed in scientific paper and the more common textbook prose styles, are in fact distinct from narrative (as, for example, Halliday & Martin, 1993, contend), then it is not surprising that the great majority of students find it difficult if not impossible to master. The introduction of these genres to learners may not be possible until the student has reached a very sophisticated use of language. This is because the students may have had to master the use of narrative before they are ready and confident to move outside it, to consider alternative ways of ordering experience. It may also be true that, as a primary act of mind, unsophisticated narratives may reflect an ordering of naive, concrete concepts, so that the abstractions associated with the scientific disciplines are not as easily assimilated into the narrative structure.

Another, conflicting viewpoint, however, denies the complete separation of scientific genres from narrative; for example, both Hardy (1975) and Moffett (1968) deny this distinction, and consider these genres as subsets of narrative. The analysis of research papers as given by

Bazerman (1990) suggests that such writing contains a narrative structure, but one that has been deliberately modified to remove as much as possible of the narrator's personal voice. However, many other essential aspects of narrative can still be found there: author, implied author, narratee, implied reader, actual reader, events, sequence and so forth. On this view, then, it is possible to argue that such scientific genres must equally represent the narrative's innate ability to order experience. If so, the reasons for its inherent difficulty for students may arise from its place on one end of a narrative continuum, from personal to impersonal voice. What is then needed, if we still value the introduction of all students to these scientific genres, are a set of pedagogic practices that can confidently move students along the continuum towards that end, and a set of psychological principles that assure us that the distance is not too great for the majority of students to traverse in their years at school. It remains for those who argue for the necessary place of the scientific genres in schools to demonstrate that these genres can be explicitly taught. There is some evidence from language education that such may not be the case, even for the more traditional literary genres.

> The Strong Hypothesis will state that explicit teaching is unnecessary; for the most part, not even possible; and where possible, not useful...The second hypothesis...is similar in stating that explicit teaching is neither necessary, nor for the most part possible or useful, and it acknowledges as well the potential for harm in such teaching. However, (it) does allow that, under certain conditions and for some learners, explicit teaching **may** enhance learning (Freedman, 1993, p. 226; emphasis in the original).

Freedman's argument is for the importance of more research into the validity of claims for the teaching of genres.

Narrative and the self

The fourth and final argument for the value of narrative depends for its force on philosophical views of the Self that have been expressed by Kerby (1991) and others. In essence, it claims that age-old questions about who we are can be answered in modern thinking by considering the narratives we tell. We are, in effect, quite literally the stories we tell.

> ..the self is given content, is delineated and embodied, primarily in narrative constructions or stories....the self is best construed as a character not unlike those we encounter almost every day in novels, plays, and other story media (Kerby, 1991, p. 1).

These stories are not only the ones told by ourselves to others. Such a wording implies that there is a self who is a Storyteller, who stands outside and composes the narratives conveyed to others. Rather, from this perspective, the very self is the product of stories told to others and stories told as internal monologues; we construct our self throughout our lives by the complex of stories we tell; in Lacan's words, "The end of the symbolic process is that non-being comes to be, that he is because he has spoken" (Lacan, in Kerby, 1991, p. 85). The self is a knot of stories told and retold that seem to define who we are; but also stories first told that tell us that something new is now a part of us.

This view of the self allows for both individual uniqueness and social being. Some of our narratives are completely our own in the sense that they form part of the inner monologues that are never communicated to anyone outside the self. Private daydreams, fantasies, events that are kept tightly concealed are examples of these individual stories. Others may guess or hypothesise about these narratives from their observations of our behaviour, especially our verbal behaviour, but unless they are ever explicitly articulated they remain internal.

Most of our individual narratives that we do make public concern our own personal history: family history, childhood memories, or the events of our last holiday. While individual, it is likely that the form of these narratives is strongly influenced by narratives that are common to the culture. Because we share childhood, and know something of holidays, the narratives take shape by assumed common understandings. Nonetheless, these narratives are individual in the sense that a narrative is made individual by the personal voice of the narrator, and the uniqueness of the events narrated. These narratives place us as individuals within a common cultural framework.

Finally, there are narratives that are not our own in the sense of being generated by us, but are the common property of the whole culture, and perhaps beyond. Certain fairytales and folk stories, myths and legends, and historical events fit this category; we are social selves through sharing in these narratives, though we may of course ascribe to them an individual meaning. Here too are the shared narratives of contemporary life within the culture: politics, perhaps, current events that are communicated world wide, such as wars or great natural disasters; the first landing on the moon may be an example of this. By incorporating these narratives into our own, so we can narrate our version, and share in the events with others, we become and demonstrate our social self.

From this perspective, schooling has, as one of its main purposes, increasing the number and richness of shared stories. Science education, more specifically, would increase the number of narratives about matter and energy that students come to tell, as an essential part of enriching their selves.

An extension of this argument would suggest that an increased understanding of science will occur when the narratives are shared as fully as possible. This may happen in either or both of two ways, as has been stated before; either allowing students to become expert readers of the scientific genres in which these narratives are traditionally told within the discipline of science, or by finding ways of translating these scientific genres into narratives that are more immediately shared by the students.

CONCLUSIONS AND SUGGESTIONS

The four arguments outlined above make strong claims about the power of narrative for science education. If they are correct, then narrative could play a useful role in helping teachers meet curricular demands for scientific literacy, as well as aiding in concept consolidation and recall. Some practical suggestions follow:

1. Assign readings from popularisers such as Stephen Jay Gould, Isaac Asimov, Lewis Thomas, and other essayists and story tellers. The assignment should seek responses from the students about both the accuracy and significance of the scientific content, as well as about the way the authors structure and personalise their reactions to the content.

2. Assign written work in the narrative mode; it is enough to put this as in the 'story' mode; the fine details of narrative need not interfere. The assignment must stress that the narratives contain only accurate science, even if the narrative is in the science fiction format. The students should be reminded that all narratives have an audience; by appropriate selection of the target audience, the teacher can aim the assigned narrative content at any given level of complexity or thoroughness. Stories written by younger writers can explore the more superficial aspects of the concept, for example. There is also the possibility of the use of such narratives for uncovering misconceptions, though to my knowledge this has not been tried.

Assessment of such stories has often led teachers to view them with uncertainty, if not suspicion. A brief and unelaborated suggested grading scheme is given here.

The **correctness** and **completeness** (i.e. the depth of understanding appropriate) of the concept(s) dealt with in the narrative receive 50%, judged in the same way as they would for a short answer question in an exam, for example.

The 50% given to the **quality of the narrative** centres on the curricular demands for some measure of scientific literacy. Fortunately, science teachers do not need to be, or become, literary critics; our everyday familiarity with stories allows us to use criteria such as the ones given here.

Narrative Coherence: 10% Does the narrative show an understandable sequence from beginning through middle to end? This is most often seen where it fails; that is, the ending seems unrelated to the beginning.

Characterisation: 20% How realistic, believable and developed are the characters? Are they stereotypes, one-dimensional, or more fully developed?

Science/Narrative integration: 10% This asks if the science content is just thrown into the narrative, or is it an integral part of the narrative. Poorly integrated stories often have the science in a separate section, written in a recognisably different style from the rest of the narrative.

Appropriateness to audience: 10% Here, the question is whether the writer has taken the level of understanding of the audience successfully into account.

Of course, all these criteria need to be made public, and the teacher must be prepared to spend time elaborating expectations as far as possible. Furthermore, all criteria must be responsive to student uncertainty with this type of assignment, and flexible with respect to student differences.

My colleague Peter Lumb and I have been using such criteria for several years in the Short Story Competition section of the Australian Chemistry in Schools Week program, sponsored by the Royal Australian Chemistry Institute. Further details of these criteria and their use are available from the author.

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COMPREHENSION OF NON-TECHNICAL WORDS IN SCIENCE: THE CASE OF STUDENTS USING A 'FOREIGN' LANGUAGE AS THE MEDIUM OF INSTRUCTION

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ABSTRACT

This paper reports on an investigation into Hong Kong students' comprehension of English non-technical words used in science. The investigation was conducted in a context in which English, a foreign language to students, is the medium of instruction, in that textbooks and examinations are all in English but the classroom language used is mainly Chinese, with frequent Chinese-English code-switching. A total of 4644 Secondary 4, 5 and 6 students participated in the study. Many students did not correctly comprehend a large proportion of the words, confused them with words that were graphologically or phonetically similar, and even took them for their antonyms. Such poor performance raises doubts as to whether the majority of Hong Kong students have attained a 'threshold level' of competence in English to benefit from learning science in English.

INTRODUCTION

Basic language skills are a prerequisite for the study of any school subject. Students require such skills to make sense of teacher talk in the classroom, read and comprehend instructional materials, prepare written work, communicate with others, etc. Yet the assumption that all students possess the necessary skills is not tenable. The problem is particularly acute in science since the language used has a characteristic formal style, makes use of a specialized vocabulary and contains syntactic structures which are more complicated than those in other subjects (Richards, 1979).

At the level of cognition, language is central to concept development. According to Vygotsky (1986), children build spontaneous concepts through their everyday interactions with people and the environment long before they can verbalise them. They have a non-conscious understanding of the concepts and it is only when they are able to express the concepts in words that their understanding is developed into a conscious form. To Vygotsky, concepts are not fully realized or understood until they are represented in words. He regards words as the means through which thought is formed and reified. A dynamic interdependent relationship exists between thought and words in that thought is developed through words and as thought develops new meanings are attached to the words and the process evolves as children's concepts develop. If the Vygotskian position is taken, students with poor language skills not only suffer from misinterpretation, but are also handicapped in their concept development.

There is a wealth of research on students' difficulties with the language in science. Studies have shown that students' understanding of science terms (e.g. energy, molecule, organism) is erroneous and incomplete (Yager & Yager, 1985) and often differs from that of the teacher (Bell & Fryberg, 1985). But the problem goes beyond the technical words and also includes the vocabulary and usage of normal English in the science context. Gardner (1972) conducted a study for the Australian Science Education Project on 500 non-technical words considered to be essential for studying science. For each word, a multiple choice question was prepared and the tests compiled were administered to large samples of students. From the results, Gardner compiled vocabulary lists of words accessible to students at different stages in secondary schools.

In the U.K., Cassels and Johnstone (1980, 1985) extended Gardner's work with a major modification: they tested each of the non-technical words in four contexts, viz. synonym, sentence, science and non-science, to investigate if comprehension of the words was context-dependent. They found that for each of the 95 words tested students' performance varied among the contexts and performance was satisfactory in all four contexts for only a few words. Later, Marshall, Gilmour and Lewis (1990) replicated Cassels and Johnstone's study (1985) on 45 of the words in Papua New Guinea where English was the official language but not the first language of the students. Cassels and Johnstone's study (1985) was also replicated in the U.K. by Pickersgill and Lock (1991) on 30 selected words to a small sample of students.

The present study uses Cassels and Johnstone's work (1985) as a basis to investigate Hong Kong students' comprehension of non-technical words in science. The study is of interest because it is set in an unusual educational context.

EDUCATIONAL CONTEXT

In Hong Kong, nearly all children receive their primary education in Chinese, but over 90% of them enter Anglo-Chinese secondary schools which use English as the medium of instruction. The popularity of these schools is attributed to a common belief that using English as the medium of instruction will improve students' proficiency in English which in turn will provide them with better educational and career opportunities. The first part of such belief is highly debatable but the second part is well supported by past history. The rapid growth of the economy in Hong Kong during the past few decades has provided many people with phenomenal opportunities for upward mobility and those proficient in English have benefited most (So, 1992).

The switch from Chinese to English poses considerable learning problems for students entering secondary schools. In the days of selective education most students could somehow cope with the switch in language after struggling for a period of time. With the introduction of free and compulsory education up to Secondary 3 in 1978, the problem has grown and become unmanageable. While some schools have adopted a policy of gradually phasing in the use of English, most have resorted unofficially to using mainly Chinese in the classroom, with frequent Chinese-English code-switching, while retaining English-medium textbooks and examinations (Johnson & Lee, 1987). Several local studies on the effects of the medium of instruction (e.g. Siu et al., 1979; Brimer, 1985) have shown that students perform better by learning in the Chinese-medium than in the English-medium. But the social and parental preference for English-medium education is so great that schools find it very difficult to take heed of such research findings (which simply proved the obvious) and change entirely to Chinese-medium instruction for fear of being deserted by parents.

The status of English in Hong Kong is unusual. Hong Kong has a population of 5.8 million, 98% of whom are Chinese. Despite its cosmopolitan and multi-racial appearance, Hong Kong is essentially a mono-lingual society in which Chinese (spoken Cantonese and written Chinese) is used in the home, community, the world of work and the media. English, while important, is restricted to uses within the government, in the law courts and in academic, commercial and financial fields and, as such, it is an 'auxiliary' language (Luke & Richards, 1982). For most students, however, their only exposure to spoken English is at school. To them, English is more a 'foreign' language than a 'second' language, since there is little or no environmental support outside school for it (Education Department, 1989).

The medium of instruction has been a very controversial issue in Hong Kong for decades, but the government has not adopted any clear language policy or undertaken any language planning until of late. In 1986, it promulgated a policy of 'positive discrimination' in favour of Chinese-medium instruction, but only a small number of schools subsequently changed to Chinese-medium instruction in a few subjects. In 1990, the government announced a drastic policy to stream students into those who would be capable of receiving English-medium instruction (estimated to be 30%) and those who would only benefit from Chinese-medium instruction using criterion-referenced tests (Education Commission, 1990). It also required schools to adopt a clear language policy, i.e. adopt the labels of English-medium, Chinese-medium, or two-medium schools for the purpose of allocating students to them. This policy, yet to be implemented, has been strongly criticised as a regressive and socially divisive measure not serving the bilingual needs of students (Luke, 1992). With the impending transfer of the sovereignty of Hong Kong from Britain to China in 1997, the policy of language in education could well take another zig-zag turn. It is anticipated that after 1997 English would still be regarded as important, especially in the commercial and financial fields, but it would take on a secondary place after Chinese (Mao, 1992). Any language policy developed must somehow take account of Hong Kong's imminent political change.

It is against such a complex background regarding the medium of instruction that the present study was conducted. The study aims to investigate how well Hong Kong students comprehend selected English non-technical words commonly used in science. These students have been studying in a peculiar environment in which both textbooks and examinations are in English but Chinese is mainly used as the classroom language.

METHOD

The word list

Rather than using Cassels and Johnstone's (1985) word list directly, an 'indigenous' list was compiled from the Hong Kong Certificate of Education Examination (HKCEE) Physics, Chemistry and Biology papers of the past five years (1988-92). Initially, a list of 118 non-technical words was produced and this was scrutinized by a panel of ten experienced English teachers. A final list of 45 words considered to be difficult to Secondary 4 students was compiled (see Table 3 for the word list). Not unexpectedly, 22 of the words were the same as those in Cassels and Johnstone (1985) and 16 words coincided with those in Marshall et al. (1990). Of the 45 words, 31 are included in Gardner's (1972) list. This exercise has paid off – the majority of the problematic words turned out to be those that have been identified locally, as discussed under 'Results and Discussion'.

The test papers

Multiple choice questions were prepared to test students' comprehension of the words in the list. For each word, questions were set in four contexts, viz. synonym, sentence, science and non-science. Examples for one of the words are given in Table 1. Most of the questions in the synonym, sentence and non-science contexts were prepared by an experienced English teacher and those in the science context by the researcher himself. As far as possible, questions in science context used the wordings in the examination papers verbatim. Out of a total of 180 questions for the 45 words, 33 questions (for 17 words) from Cassels and Johnstone's study were used, 8 with minor changes to suit the Hong Kong context. This was to expedite the preparation of the questions, which was a difficult and time-consuming exercise, so that testing could be conducted in schools as scheduled.

From the questions prepared, four parallel test papers were compiled, each paper testing the comprehension of the 45 words in one of the contexts. Five control questions, from Cassels and Johnstone's study, were added to each paper. These questions were kept in one context only and tested the comprehension of five words: 'percentage', 'excite', 'capable', 'repel' and 'average'. All the questions were scrutinised for accuracy, suitability and validity by two

TABLE 1
THE FOUR CONTEXTS FOR THE WORD 'INSTANT'
(The percentage selecting each option is given; the correct answer is asterisked)

---

1. Synonym context
'Instant' can mean
A. happening. (12%)
B. incident. (12%)
C. moment. (64%)*
D. instinct. (12%)

2. Sentence context
Which sentence uses the word 'instant' correctly?
A. With more instant, we can do the work better. (16%)
B. Tommy put his homework aside the instant his mother left home. (26%)*
C. Lucy seems to have an instant for choosing the correct answer. (33%)
D. May I keep you an instant to answer a few questions? (25%)

3. Science context
The diagram shows the wave at two different instants. This means the wave is drawn
A. at two different moments. (44%)*
B. at two different places. (14%)
C. using two different methods. (16%)
D. in two different patterns. (26%)

4. Non-science context
Wait here, I shall be back in an instant. This means I shall be back
A. in a second. (52%)*
B. after some time. (32%)
C. in an hour or two. (6%)
D. at your request. (10%)

English language teacher educators. The draft test papers were tried out in two schools. In the light of the comments and suggestions and the item statistics of the trial test, some minor changes were made to the wordings of several questions.

Sampling procedure
The study used a 12% proportional randomized sample of schools, stratified by school type (government, grant and aided schools) and area (19 areas in total). However, 9 out of 46 schools had to be secured by the researcher through personal contacts rather than a random process, to fill the 'missing strata' due to non-response or refusal. It should be noted that Cassels and Johnstone (1985) used a volunteered sample and Marshall et al. (1990) presumably used a convenience or volunteered sample since no sampling information was given.

Each of the 46 participating schools was randomly assigned one of four test papers. In each school, the test was administered to one science class each of Secondary 4, 5 and 6. The testing took place in March/April, 1993. A total of 4644 students took the tests of which 1844, 1579 and 1221 were S4, S5 and S6 students respectively.

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RESULTS AND DISCUSSION

Reliability coefficients

The four papers were found to have very high internal consistency: the Cronbach alphas were 0.89, 0.91, 0.89 and 0.87 respectively.

Item statistics

The mean facility of the 180 questions in the four test papers was 54.5% (standard deviation 17.6%) and the mean discrimination index was 0.40 (standard deviation 0.13). The tests in this study were criterion-referenced rather than norm-referenced. As such, questions with low discrimination index should not be dismissed as poor questions without closely examining the wordings of the questions and the response patterns; they could well be questions on problematic words which require attention. The results showed that the discrimination indices of 144 questions (80%) well exceeded 0.30, 23 questions (12.8%) were between 0.20 and 0.29 and 13 questions (7.2%) were less than 0.20. The 13 non-discriminating questions all had low facilities. This overall pattern suggests that the multiple choice questions in the papers were generally well set.

The control questions

The first five questions were common to each paper and used as a control to check whether the allocation of the four papers to the participating schools were random. It was found that there was no significant differences between the groups of students who did the four papers.

The five control questions were identical with those used in Cassels and Johnstone (1985) and Marshall et al. (1990) and so comparison can be made with them. It can be seen from Table 2 that Hong Kong students' performance was substantially poorer than in the other two studies. The overall performance on four of the five words was lower than 70%. Even for Secondary 6 students, performance on 'percentage', 'excite' and 'repel' was unsatisfactory. This is an alarming result as it was thought that these words were rather simple and such a poor result was not anticipated.

TABLE 2
PERCENTAGE OF CORRECT RESPONSES TO THE FIVE CONTROL QUESTIONS

Question/Word	Present Study S4	Present Study S5	Present Study S6	Overall	Cassels & Johnstone*	Marshall et al.#
1. percentage	41	40	57	45	93	92
2. excite	41	47	63	49	93	84
3. capable	54	61	81	64	95	82
4. repel	40	47	54	46	81	69
5. average	71	75	88	77	97	86

* mean percentages extracted from Cassels and Johnstone (1985) for the equivalent S4 to S6 students

# mean percentages for Grade 7 to 12 and University Year 1 students

Performance across grades

Performance is taken to be 'satisfactory' if the percentage of correct responses is equal or higher than 70%. Table 3 gives the percentages of correct responses to the questions by grade and by context. As would be expected, performance improved with the grade level. This was true for the overall performance (increase from 45% in S4 to 53% in S5 and to 71%

in S6) as well as for performance on individual words. The improvement was generally more marked from S5 to S6 than from S4 to S5. This is not unexpected since entry to S6 is selective, based on the HKCEE results.

Performance across contexts

It can be seen from Table 3 that none of the 45 words had satisfactory performance in all four contexts. Performance was satisfactory in three contexts for four words ('effect', 'excess', 'initial', 'maintain'), and in two contexts for four words ('essential', 'liberate', 'random', 'uniform'). Of the remainder, 19 words (42%) had satisfactory performance in one context and 19 words (40%) were unsatisfactory in all four contexts. This clearly indicates that the Hong Kong students in the sample had very poor comprehension of the non-technical words tested.

The overall performance of the non-science context was better than that of the science context, which is contrary to the result obtained by Marshall et al. (1990) for Papua New Guinea students. Among the four contexts, overall performance was worst in the sentence context and poor in the synonym context. It is understandable that weak responses occur in the synonym since there is no context from which a meaning can be deduced. However, the poor performance in the sentence context showed that the Hong Kong students in the sample had problems not only with comprehending the meaning of the words but also with using them correctly. The correct usage of a word is more demanding than its comprehension. Hong Kong students often relate English words to the meaning of the Chinese translation but are unable to use them correctly in sentences.

Words requiring attention

Words with unsatisfactory performance (i.e. percentage of correct responses lower than 70%) in at least three out of the four contexts are designated 'problematic' words. These words are listed in Table 4 by grade and denoted by Xs. It can be seen that only three words ('essential', 'initial' and 'uniform') do not require attention in all three grades. The number of words requiring attention are 42 (93%) in S4, 37 (82%) in S5 and 13 (29%) in S6. In Marshall et al. (1990), the number of words requiring attention in the corresponding grades are 25, 8 and 5. Although direct comparison is not possible since the word list and questions are not all the same, this result again points to the poor performance of the Hong Kong students in the sample.

Confused words

The results showed that students often confused the words tested with words which were graphologically or phonetically similar: for example 'instinct' with 'instant'; 'insist' and 'resist' with 'persist'; 'receive' with 'achieve'; 'assure' with 'assume'; 'deprive' with 'derive'; 'advice' with 'device'; 'assert' with 'exert', 'interrupt' with 'interpret'; 'distinguish' with 'determine'; 'resolve' with 'evolve'; 'generalise' with 'generate'; 'evaluate' with 'evacuate'; 'transmit' with 'transform'; 'reserve' with 'conserve'. In some cases, students even confused the words with their antonyms: for example 'fill' with 'evacuate'; 'disappear' with 'persist'; 'take in' with 'emit'. It is not possible to ascertain that such meanings of the words were strongly held by the students; when faced with total incomprehension, students might simply select the option that appeared to be similar. But what is certain is that students' comprehension of the words tested was very poor.

CONCLUSION

Students in the sample generally performed very poorly in the tests. They failed to comprehend a large proportion of the English non-technical words, confused them with words that were phonetically or graphologically similar and even took them as their antonyms. Students also had problems with the correct usage of the words in sentences. This may have

TABLE 3
PERCENTAGE CORRECT BY CONTEXT AND BY GRADE

	Context				Grade			Overall
	Synonym	Sentence	Science	Non-sci	S4	S5	S6	
account	48	50	44	76	43	55	74	55
achieve	40	49	47	58	36	42	52	48
action	15	53	58	38	41	45	65	42
appropriate	69	27	58	71	47	56	74	57
associate	71	55	52	45	44	54	76	56
assume	36	51	68	66	50	50	68	55
characteristic	56	60	65	84	57	67	78	66
component	66	53	58	73	53	59	80	63
composition	63	72	66	63	57	64	80	66
conserve	34	43	60	48	36	45	62	46
contribute	37	35	45	73	38	44	66	47
deliver	45	46	29	69	39	44	64	47
denote	57	40	56	66	45	55	70	55
derive	34	27	39	70	37	37	56	42
determine	58	26	64	79	50	55	68	56
device	62	52	46	69	41	59	80	57
effect	21	74	74	74	54	58	71	60
emit	60	67	80	68	53	69	90	68
essential	63	68	83	86	66	75	89	75
establish	77	39	56	44	48	53	67	54
estimate	54	22	39	53	33	40	61	42
evacuate	30	23	43	28	27	27	42	31
evolve	25	38	80	39	37	49	56	46
excess	91	64	73	80	67	78	92	77
exert	26	41	57	42	33	36	60	41
generate	52	41	67	67	42	55	80	56
illustrate	20	53	51	44	35	51	57	43
initial	86	64	79	82	69	78	92	78
instant	63	26	44	52	34	46	66	47
instantaneous	56	40	58	31	36	46	63	46
interpret	44	28	56	60	41	44	60	47
liberate	67	36	74	73	51	62	82	63
maintain	64	71	77	78	63	70	90	73
negligible	60	61	81	44	46	61	87	62
persist	28	24	31	25	20	27	38	27
random	68	74	63	74	56	71	89	70
relative	63	30	52	62	43	46	73	52
release	44	57	88	74	59	61	79	65
resume	25	28	53	77	40	45	56	46
sequence	72	48	49	56	43	57	76	56
subsequent	58	27	32	69	40	47	60	47
transform	43	29	75	32	38	42	57	44
uniform	58	32	86	86	60	63	77	65
variation	57	42	32	82	44	54	69	54
vigorous	78	58	68	55	55	63	82	65
Mean (std dev)	52 (18)	45 (15)	59 (16)	62 (17)	45 (11)	53 (12)	71 (13)	55 (11)
Max/minimum	91/15	74/22	88/29	86/25	69/20	78/27	92/38	78/27

TABLE 4
WORDS REQUIRING SPECIAL ATTENTION

	Grade		
	S4	S5	S6
account	X	X	
achieve	X	X	X
action	X	X	X
appropriate	X	X	
associate	X	X	
assume	X	X	
characteristic	X	X	
component	X	X	
composition	X	X	
conserve	X	X	
contribute	X	X	X
deliver	X	X	X
denote	X	X	
derive	X	X	X
determine	X	X	
device	X	X	
effect	X		
emit	X		
essential	X		
establish	X	X	
estimate	X	X	
evacuate	X	X	X
evolve	X	X	X
excess	X		
exert	X	X	X
generate	X	X	
illustrate	X	X	X
initial			
instant	X	X	
instantaneous	X	X	
interpret	X	X	
liberate	X		
maintain	X	X	
negligible	X	X	
persist	X	X	X
random	X		
relative	X	X	
release	X	X	
resume	X	X	X
sequence	X	X	
subsequent	X	X	X
transform	X	X	X
uniform			
variation	X	X	
vigorous	X	X	
No. of words	42	37	13

to do with the dominant use of Chinese in the classroom and students had very little practice in the usage of the words in English. Students' poor performance on the tests raises serious doubts as to whether the majority of them have attained a 'threshold level' of competence in English to benefit from learning science in English.

The medium of instruction is a very controversial and complex issue in Hong Kong and the choice of language is likely to be determined more by social, economic and political factors than findings of educational research. What the present study can contribute towards the debate is to indicate unequivocally that many Hong Kong students do not have adequate English to enable them to learn science, and presumably other subjects, in English. Arguably, two diametrically opposite courses of action may be taken to address the language problem. First, students diagnosed to have low proficiency in English may be channelled into Chinese-medium education but this will surely be met with strong opposition from parents and result in social segregation between students in Chinese- and English-medium schools or classes within the same school. Alternatively, steps may be taken to improve the teaching of English in schools and this will require effective language planning, systematic research and massive investment of resources. If the latter course of action is taken, findings of this research may be used to inform teachers of the sort of difficulties students face in comprehending the non-technical words in science.

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CHILDREN'S INTERESTS IN GEOLOGY AND BIOLOGY

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ABSTRACT

A study of students from a primary school and its local secondary school was conducted to investigate students' relative interests in geology and biology during the years prior to Year 10. Students from Years 1, 3, 5, 7 and 9 were interviewed, using an innovative interview technique, and results show that interest in both subjects appears to be fairly evenly distributed throughout all years. This paper reports on the study conducted and illustrates the success of the interview technique developed to accommodate all students, especially those from younger year levels.

INTRODUCTION

Students' aversion to specific scientific concepts has been the subject of widespread science education research. For example, Okebukola and Jegede (1989, p. 85) cite thirteen studies across all areas of science in which high school students have been shown to "dread" studying certain scientific topics. There is, however, little in the literature which could be used to explain the apparent major aversion to geology which can be inferred from the difference that exists between the enrolments in Years 11 and 12 for Biological Science and Earth Science in Queensland schools. In 1992, 1319 students were enrolled in Earth Science and 30 031 in Biological Science and in 1994 the figures were 1224 and 26 061 respectively (data obtained from Board of Senior Secondary School Studies, 1994). This phenomenon is not new to Queensland (De Laeter & Dekkers, 1982). Moreover, it appears to correspond with a world wide trend. Brown (1984, p. 9) reports that "the existence of geology in the [UK] secondary school curriculum is in a state of uncertainty"; Merchant (1984, p. 78) claims that UK school administrators regard geology as a "dispensable" subject and O'Connell found, from vigorous discussion of the paper presented by Dineley (1989) during the International Geological Convention in Washington, D.C., that poor opinions of geology were widespread throughout the educational systems of many countries.

The reasons for the imbalance in enrolments between geology and biology are undoubtedly complex. Nevertheless, the extent of the imbalance is a source of concern, particularly amongst educators in the field of geology. Their concern, however, appears to be based on a fundamental assumption which has, to the best of our knowledge, never been tested. It is the assumption that students, at some stage during their development, are substantially equally interested in both geology and biology. It has been implied that students' interests must have changed or been changed between the time when interests in both subjects were equivalent and the time when enrolment choices had to be made. Furthermore, it has been argued that if the stage at which the interest levels change could be identified, then action could be undertaken to determine and rectify the factors which contribute to the subsequent imbalance of enrolments.

This research project was set up as a case study of students' interests in biology and geology in years 1, 3, 5, 7 and 9 in one primary school and its local secondary school. The purpose was to test the assumption that students do have equal interests in both subjects at some time prior to Year 10, the year when they are required to choose their senior science subjects.

METHOD

Background

Over the last thirty years considerable effort has been expended to determine students' interest in and attitudes towards science. Krynowsky (1988) cites four major reviews of over 700 studies which have highlighted the methods, results and problems of this research. Even so, Griffiths and Barry (1992, p. 1) believe that "we have not made much progress towards generally accepted conclusions". They note that there have been many reasons for this lack of consensus including problems with the methods used and the philosophical bases of many of the studies. However, they also point out that most of the studies which have investigated students' interests have used scales which have been "developed from the perspective of the expert". In support of this they quote Munby's earlier claim that research in this area has suffered from "the doctrine of immaculate perception, namely that researchers tend to assume that students attach the same meaning to test item statements as do the developers of the test" (Munby, 1982, cited by Griffiths & Barry, 1992, p. 1).

The view that researchers should be more concerned with identifying students' perceptions than with investigating their own, has found strong support in the rise of the constructivist educational paradigm. Driver and Easley (1978, p. 76) first expressed this sentiment when they recommended that it was time to pay more attention to "the actual content of children's ideas and explanations" and less to "the supposed underlying logical structures" as defined by the researchers. From the thousands of research studies based on constructivism which now exist (see bibliography compiled by Pfundt & Duit, 1991), it is obvious that this attitude towards research is now widely supported.

As this project set out to determine students' interests with respect to biology and geology, it was envisaged that an evaluation instrument could be 'borrowed' from another case study. However, because of the particular conditions under which the research was to be conducted, no satisfactory existing instrument was found. One was therefore developed to meet the following criteria:

* It was to be used with children in Years 1, 3, 5, 7 and 9. This placed restrictions on the nature of the biological and geological concepts which could be included. It also meant that the instrument had to be independent of students' linguistic abilities.

* It required a purpose which all students would regard as being "potentially fruitful" (Ginsberg, 1992, p. 2)

* Its "trustworthiness" (Lincoln & Guba, 1985, p. 285) had to be evident at all levels of usage.

The resulting instrument can best be described as an eclectic interview. The procedures were broadly based on those of a cognitive clinical interview (Ginsburg, 1981, 1992). "Trustworthiness" was fostered by using a modified "interview about instances" (Osborne & Gilbert, 1980) and a modified "interview about events" (Osborne & Freyberg, 1985). These techniques allowed students to establish their own interpretations of concepts and subsequent discussions to be based on those interpretations without intervention by the interviewer.

The "potentially fruitful" purpose for the interview was achieved through adopting Walberg's (1981) idea that activities which are voluntarily undertaken by an individual make good predictors of continued study and thereby imply high levels of interest (Walberg, Pascarella, Junker, Haertel & Boulanger, 1983, p. 13).

The instrument

The interview was based on fifteen pictorial cards, representing equal numbers of geological, biological and humanities concepts. The humanities concepts were included so that children had the option during the interview to reject either or both sciences if they wished.

The concepts were chosen by asking seven adults and five children to list the topics they thought of when the subjects of 'geology', 'biology' and 'humanities' were raised. The five most commonly listed concepts in each subject were then selected. No implication is intended that the five concepts chosen represent an exhaustive or definitive description of each subject. The concepts chosen in each subject are listed in Table 1. For each concept, three or four appropriate photographs were compiled to form a picture card.

These cards were then tried out on three adult research assistants and two geology staff members to see if they could identify the concept each card was supposed to represent. They were also asked to identify any pictures on the card which did not contribute to the concept. Where individuals expressed difficulty in either identifying a concept or associating a photograph with a concept, that card was changed. When agreement was reached the cards were tried out on four Year 1 students. None of these students had any difficulty in identifying the concept of each picture card, but for young children it was thought that the label of "people who help us" was more appropriate than "emergency services" and "shapes of the land" would be more meaningful than "landforms". For the older grade students, the term "furry animals" was replaced by "marsupials". (The cards are available from the first author.)

The interview

The interview consisted of several steps.

1. The interviewer put the child at ease, explained the procedures, pointed out that this activity was different to 'normal' school activities in that it was confidential and that the child could withdraw from the interview at any time he/she wished, and asked the child for permission to video-tape the interview.

2. The purpose of the interview was explained to each child as a survey to find out what sort of educational activity he/she would like to undertake when there was some free time available in class. The interviewer explained that there was a range of topics available and that for each topic the child could choose books or a video or a game. These options were demonstrated for the child using a book, video and game relating to a non scientific topic which was not included in the survey.

3. The fifteen picture cards were randomly spread around a table. The student was given fifteen labels, one at a time, and asked to attach each label to an appropriate card. If there was any doubt, then that label was placed to one side. When the child had labelled all of the cards that he/she could without assistance, the interviewer discussed the unmatched labels and cards and explained, where necessary, the concepts pictured on the card. Student concepts of what the cards represented were not questioned.

   In this "interview about instances" the "trustworthiness" of the cards for each student was established. As children matched the concept of each card with a label without criticism or question about what their concept of the card actually was, it was inferred that they had a definite personal concept of the pictorial concept which the card presented. No attempt was made to influence or change that concept.

4. Children were asked to select five cards representing the concept topics they would most like to explore if they had some free time in class and were able to do anything they wished. They were reminded that each topic came in the form of books, a video and a game but not asked, at this stage, to nominate which they would like to use. The interviewer encouraged students to pick out all the topics they were interested in and then eliminate some until only the five most desired concept topics remained. The interviewer actively interacted with the children during this process, without influencing the choices made.

5. The children were asked to rank order the five cards chosen according to their topic preference for free time activities. By doing so, children created their own "event" as the ranking of the concepts/cards then became the subject of the subsequent interview. In this way an "interview about events" (after Osborne & Freyberg, 1985) was conducted and the "trustworthiness" of the interview with respect to finding out about children's interests further substantiated. The selection and sequencing of each card was noted and discussed. From these discussions the reasons underlying students' interest in a concept were elicited.

6. To complete the interview, children were asked to rank order the three available forms of media with respect to their preference for free time activity. The interviewer recorded the order chosen. (The data from this aspect of the study will be reported elsewhere.)

7. Each child was thanked for assisting with the survey.

Interview sample

For convenience, a cross-sectional sample of children was chosen from alternate years from Year 1 to Year 9 in one local area. Two State schools were involved. These schools share a common boundary and are situated in an old suburb of Brisbane that has a fairly stable population.

The class teachers responsible for Years 1, 3, 5, 7 and 9 were asked to nominate three males and three females from each class for an interview, giving a total of 30 students. Teachers were asked to choose students across the range of class abilities and interests. All teachers stated that they had done this. Permission to interview students was obtained from educational authorities and from parents and children. All of the children interviewed were keen to be involved in the project, even though they were not informed beforehand about the nature of the project. After the interviews the Year 1 teacher commented to the interviewer that her students had really enjoyed taking part in the project.

Data collection

All interviews were video recorded using a stationary video camera focussed on the table. In most cases, this was satisfactory in that when children left the field of view, they still remained in audio contact with the camera. All interviews were transcribed.

For each child, the interviewer manually recorded the concepts of the five cards selected and the rank order of the concept preferences.

RESULTS

Quantitative and qualitative data were obtained from the interviews.

Quantitative data

Table 1 shows the popularity score for each concept per grade and the frequency of its selection across all grades. The popularity score was calculated by awarding a score of 5 for first preference, 4 for second, 3, 2 and 1 for third, fourth and fifth respectively.

TABLE 1
POPULARITY SCORES FOR EACH CONCEPT BY YEAR LEVELS

Concept		Popularity Scores					Totals	
		Y1	Y3	Y5	Y7	Y9	Popularity Score	Times Selected
B:	Furry animals	12	15	18	10	5	60	18
G:	Fossils	13	16	10	6	9	54	16
G:	Gemstones	14	12	7	6	5	44	15
G:	Volcanoes	7	8	4	11	12	42	13
B:	Reptiles	10	8	9	7	3	37	13
H:	Art	7	9	0	14	6	36	12
G:	Landforms	3	1	7	3	17	31	11
B:	Spiders	6	2	10	11	1	30	11
H:	Sports	0	4	5	6	11	26	8
B:	Human Body	1	11	1	3	7	23	9
H:	Music	0	1	6	7	6	20	7
H:	Transport	4	0	5	4	5	18	4
H:	Emergency Services	8	0	7	0	2	17	7
B:	Plants	5	0	1	2	1	9	5
G:	Mining	0	3	0	0	0	3	1

Note: B = Biology; G = Geology; H = Humanities

By combining the popularity scores of all concepts in each subject, popularity scores for geology, biology and humanities for each Year level were obtained and graphed. This is shown in Fig. 1. The subscores for females and males with respect to biology and geology for each Year level were calculated, but no further action was taken when they were found to mirror total Year scores.

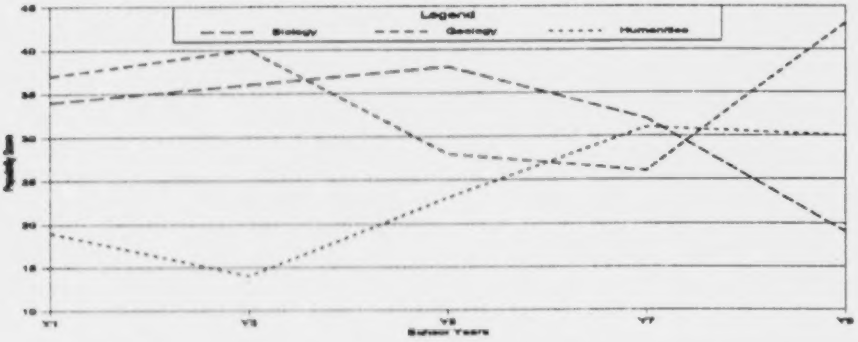

Fig. 1 Popularity Score in Biology, Geology & Humanities in School Years

Qualitative data

As the discussions with students were conducted with respect to specific concepts, the qualitative data refer to those conceptual topics rather than the assumption about biology and geology. However, an examination of the transcripts showed that children in this case study tended to defend their interest in concepts in a fairly restricted number of ways, one of which has implications for students' interest in geology. Five positive reasons were offered for studying a topic and three negative reasons were put forward to defend the rejection of a topic.

The positive reasons were:

- Emotive e.g. It's cuddly; it's nice; it looks pretty
- Personal or family experiences e.g. We go there for holidays; my dad has a collection.
- Curiosity and awareness e.g. I want to know; It's fascinating to realize that; I'd like to find out.
- Implied excitement e.g. They're venomous; they scare me; I like it when they explode
- Desire to be different e.g. I like unusual things; others will choose that.

The negative reasons were:

- A "been there, done that" attitude, e.g. I've done a project on it and it is boring; I've seen mines and everything like that, it just doesn't interest me that much.
- Aversion through fear, e.g. You could get stuck in a hole; It can collapse; they're just ugly and they bite.
- Bad public image factor, e.g. It's pollution and it wastes electricity a bit; they do wipe out a lot of trees and stuff doing it so it is a bit bad for the environment.

DISCUSSION

The distribution of the concepts in Table 1 and the graph of the popularity of all three subjects, as shown in Fig. 1, give strong support to the geology educators' assumption that at some stage prior to Year 10, students are comparatively equally interested in biology and geology. In fact, this study indicates that this equivalence of interest extends from Year 1 to Year 9 and is in existence just prior to the time when students are required to make their decisions about their upper secondary subjects. It even appears that, for the students in this study, interest in geology is as high, if not higher than interest in biology in Year 9. Furthermore, this finding was corroborated by the qualitative data in that the most scientific reason given for choosing a topic, that of "curiosity and awareness" was most often associated with geological topics.

Therefore, our only interpretation of these findings with respect to the imbalance of enrolments between geology and biology in Year 11 is that it appears that interest in a subject area has little effect on subsequent choice of school subjects. The NBEET Report, *Issues in Science and Technology Education* (1993, p. viii), strongly supports this position when it states "In our view, no matter how much improvement can be made in science and technology curricula and teachers' professional experience, students will continue to avoid further science and technology studies and science and technology careers unless these are perceived as attractive options".

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CONSISTENCY OF CHILDREN'S USE OF SCIENCE CONCEPTIONS: PROBLEMS WITH THE NOTION OF "CONCEPTUAL CHANGE"

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ABSTRACT

A study of primary school children's explanations of a range of phenomena concerning air pressure revealed considerable fluidity in their use of conceptions. A measure of consistency was developed and applied to children's written and oral explanations in a range of contexts. While the results showed a general trend with age toward more abstract, 'generalizable' conceptions, the notion of parsimony was found to be problematic on a number of levels. Children do not apply a single conception to a phenomenon, but rather operate with multiple conceptions in their explanations, complicating the whole notion of consistency. Moreover, as they develop and apply more advanced conceptions, children inevitably display temporary reductions in consistency. These findings suggest a rather more complex model of conceptual advance than implied in the literature on 'conceptual change'.

INTRODUCTION

William of Occam was the alleged author of the idea that "entities are not to be multiplied beyond necessity". This idea, popularly known as 'Occam's razor', serves as one of the guiding principles in judging scientific theories. The principle is also referred to as 'parsimony'; a preferred scientific theory contains no redundant ideas, and operates across a wide range of contexts. The notion of 'alternative frameworks' implies much the same notion of parsimony applied to children's ideas. On the other hand, children's science ideas are often described as opportunistic and redundant, with different conceptions generated for each context without regard to consistency.

The literature on conceptual change tends to operate on the underlying assumption that a conception, once gained, is applied across contexts as a 'framework' or informal theory. While the work of conceptual change theorists such as Posner, Strike, Hewson and Gertzog (1982) and Carey (1985, 1986) is helpful in clarifying ways in which conceptual development might occur, with few exceptions they do not furnish evidence to show that students hold consistent views across a range of phenomena. The question is often begged as to whether a coherent belief system really exists. But just how consistent are students' ideas? To what extent can we really credit them with holding one fundamental conception, in opposition to a science conception, that can by degrees be moved toward the more scientific one?

There have been, alongside the notion of alternative frameworks that need to be replaced by scientific conceptions, a growing number of studies providing clear evidence that the process is more complex than this. Engel Clough and Driver (1986) obtained equivocal results with respect to the consistency of students' use of alternative frameworks. They found that students were using different conceptions in response to parallel questions, and that contextual features of the tasks seemed to be influencing students' consistency, a finding that makes sense in terms of the way physical features and situational analogies ('trapped' bodies of water in upturned glasses) became part of the explanations about air reported in a study preliminary to this one (Tytler, 1992).

In a similar vein, Scott (1987), in discussing a case study of one girl's development of understandings of the particulate nature of matter, concluded: "Rather than conceptual change there appeared to be a parallel development of particle ideas alongside already existing ones. ...(resulting) in alternative explanations which can be employed as and when appropriate" (p. 417). Driver (1989) argues that, while studies like Scott's show the unpredictable ways in which individuals' conceptions might change, there seem to be definite patterns in the conceptual pathways that students on the whole follow during a restructuring process.

Lijnse (1990) used six 'alternative frameworks' for energy identified by Watts (1983) as a basis for analysing views about energy expressed by secondary school students. 75% of students wrote statements in more than one framework. He therefore disputes Watt's interpretation of the energy frameworks as "structures which provide sensible and coherent explanations", but rather argues that: "the frameworks mentioned function as important basic ideas which pupils seem to have at their disposal in a flexible way, dependent on the situation. Pupils' thinking is not characterized by an internally logical or consistent framework" (p. 575).

Students' views on motion

Many studies have focussed on students' intuitive concepts of force and motion, and the difficulty of shifting these (e.g. Gunstone, Champagne & Klopfer, 1981). The transition to a Newtonian view of mechanics has operated as an exemplar for conceptual change theorists, who point to striking correspondences between students' conceptions and earlier historical theories of motion, notably those of Aristotle, and of medieval impetus theorists. The ascendancy of the Galilean/Newtonian theories of motion is held to be a classic example of a revolutionary shift in the history of science (Kuhn, 1970), and it has become common in discussing the difficulty individual students have in embracing a Newtonian view of motion to refer to the shift from an Aristotelian to a Newtonian world view. While this analysis helps to highlight the difficulty students have with Newtonian conceptions, the further step, which is sometimes explicitly claimed (e.g. McCloskey, 1983) but more often assumed, that students' intuitive ideas about motion represent a well articulated theory, is being increasingly challenged (Fischbein, Stavy & Ma-Naim, 1989; Licht & Thijs, 1990; Finegold & Gorsky, 1991; Palmer, 1993).

DiSessa (1983, 1988), more radically, characterizes students' knowledge as being inherently situation bound, involving the application of sets of 'phenomenological primitives'. For DiSessa, expert knowledge is characterized by the achievement of a complex web of hierarchical rules governing the operation of these p-prims.

How do we characterize an 'alternative conceptual framework'?

Clearly, we can identify a range of ideas, 'intuitive conceptions', which naive students bring to a study of science and which are identifiable across international boundaries and have particular age-specific patterns of commitment. Just how consistently these are applied across contexts is a matter of debate, and seems to depend on the particular conceptions (e.g. young children's use of the concept animal or their mental model of the earth is held to be consistent, whereas studies of students' conceptions of motion, and of air pressure (Tytler, 1992), have demonstrated significant inconsistency) and, perhaps, on the age or experience of the student.

Engel Clough and Driver (1986) acknowledge the possibility that frameworks identified from interview transcripts may be "little more than artifacts of the methodology, transient solutions devised in an interview where an answer of some kind is a social imperative" (p. 475), but they go on to argue that if it can be shown that students use the same ideas over a range of contexts which scientists construe similarly, then that would lend support to the notion of frameworks as "commonly available ways of thinking" (p.475).

A full account of the nature of conceptual change, even in cases clearly involving radical restructuring, must involve a consideration of the range of phenomena any conceptual shift is applied to. Is the contextual dependence of conceptions simply 'noise' against the more substantive background of conceptual change conceived of as theory change, or is context a crucial aspect of conceptions about phenomena?

STUDYING CHILDREN'S EXPLANATIONS OF AIR PRESSURE PHENOMENA

Children from Years prep., 3/4 and 5/6, and adult teachers, experimented with different subsets of tasks involving air pressure. They were asked to generate explanations of aspects of these initial tasks, in groups. They then wrote down (or dictated in the case of the preps) their individual explanations. In a further session they discussed these explanations in other groups where they were exposed to the wider range of tasks. Some children were interviewed after these activities, and again six months later.

The air pressure tasks

Over the sessions children were exposed to a total of 16 tasks. These included:

- **The dry tissue**: A glass containing a dry tissue is plunged upside-down into water. The tissue, on removal, has remained dry.
- **Upturned glass**: A glass full of water with a piece of paper across the rim is upturned. The water does not spill out.
- **Blocked funnel**: Water is poured into a funnel tightly sealed into a jar. It does not pour through because of the pressure of air trapped inside. If the finger is taken off a hole in the lid the water pours through unimpeded.
- **Bird feeder**: A commercial bird feeder is filled and up-ended. The tray fills but no more water comes out.
- **Magic finger**: A can full of water has three holes punched in the bottom and one in the top. Flow of water through the bottom holes is controlled by closing and opening the top hole with a finger.
- **The sticky dart**: A rubber suction cap is pressed onto a tile. It is difficult to remove.

Children's explanatory conceptions

In the explanations of these tasks, ten explanatory conceptions ('interpretive frameworks') were identified. The following list places these conceptions in a rough order of increasing sophistication :

C1.	Description of observations ("the water spurted out")
C2.	Human agent ("because we blew hard")
C3.	Intentionality attributed to objects ("the air wanted to escape")
C4.	Unfocussed references: to 'air' ("the air made it happen"), or
C4A	to water as a causal agent ("the water blocked it")
C5	'Trapped' image ("the air and water were trapped in the can")
C6	Movement of air ("the air couldn't circulate and so couldn't push")
C7	Action of enclosed air: force ("the air in the jar forced the water out"), or
C7A	suction effect ("the air under the dart sucks it onto the surface", "the air inside the cup holds the water up"), or

C7B pressure reduction/creation ("by blowing we increased the pressure", "the air is intense and pushes it out")
C8 Action of outside air: force ("the air pushed against the dart"), or
C8A pressure ("the pressure from the outside air held the card in place")
C9 Competition for space ("the water can't get out unless air can get in to take its place")
C10 Differential pressure ("the outside air presses harder than the air and water inside")

A MEASURE OF CONSISTENCY

Children wrote explanations for an initial subset of six tasks they had experimented with in the group sessions. These explanations were analysed for consistency of use of conceptions. In order to compare individual children, a measure was needed which represented the extent to which they clustered the tasks around a small number of conceptions. For this purpose, I chose as a **consistency rating** (C_R) the variance of the number of times they used particular conceptions. For example, if a child explains the six tasks according to the conception pattern "C5, C6, C7A, C5, C7A, C4", then the profile of use of six possible conceptions c_1 to c_6 is:

c_1	c_2	c_3	c_4	c_5	c_6
2	2	1	1	0	0

where c_1 and c_2 are the two conceptions C5 ('trapped') and C7A ('suction') which are used twice, and C4 and C6 become c_3 and c_4 respectively. c_5 and c_6 are notional conceptions which could have been used to explain some of the tasks but were not, because of the multiple use of C5 and C7A. The consistency rating for this set of explanations, which is the variance of the numbers 2, 2, 1, 1, 0, 0, is 0.8. This child would score higher in consistency if, for example, he/she used C4 instead of C6 for one of the tasks, giving a pattern of 2, 2, 2, 0, 0, 0. For six explanations, the C_R values can range from 0 (no consistency, with a different conception used for each task) to 6 (complete consistency). While this is an unorthodox use of the notion of 'variance', and one for which no precedence exists in the literature, it does have the advantage of giving a measure of consistency that accords with a common sense 'eyeballing' of the data. In order to demonstrate this point, Table 1 sets out the consistency rating for different patterns of use of conceptions for six tasks.

TABLE 1
CONSISTENCY RATINGS FOR DIFFERENT PATTERNS OF EXPLANATION OF SIX TASKS

	c_1	c_2	c_3	c_4	c_5	c_6	**Consistency rating C_R**
Pattern 1	1	1	1	1	1	1	0
Pattern 2	2	1	1	1	1	0	0.4
Pattern 3	2	2	1	1	0	0	0.8
Pattern 4	3	1	1	1	0	0	1.2
Pattern 5	3	2	1	0	0	0	1.6
Pattern 6	4	1	1	0	0	0	2.4
Pattern 7	4	2	0	0	0	0	2.8
Pattern 8	5	1	0	0	0	0	4.0
Pattern 9	6	0	0	0	0	0	6.0

This measure of consistency proved useful for comparing children with explanations over different numbers of tasks. To illustrate this point, Table 2 represents possible patterns for one child's construction of explanations over an increasing number of tasks.

TABLE 2
CONSISTENCY RATINGS FOR PATTERNS OF EXPLANATION
OF DIFFERENT NUMBERS OF TASKS

Task:	1	2	3	4	5	6	C_R
Pattern 1	C5	C5					2.0
Pattern 2	C5	C5	C6				1.0
Pattern 3	C5	C5	C6	C6			1.3
Pattern 4	C5	C5	C6	C6	C5		2.0
Pattern 5	C5	C5	C6	C6	C5	C5	2.8

This child had achieved consistency in explaining two tasks, but when confronted with a third used a different idea altogether. The rating therefore drops. The child then uses the second conception to explain a fourth task and the rating increases, and so on. The rating thus accords with commonsense notions of consistency. We can, however, interpret the table as representing consistency ratings for patterns of use of conceptions by different children, over different numbers of tasks. C_R can thus be used to compare children who have constructed different numbers of explanations.

CONSISTENCY OF USE OF EXPLANATORY CONCEPTIONS ABOUT AIR

It became clear, in looking at the patterns of conceptions used in the written explanations, that the younger children were achieving considerable consistency from using the primitive conceptions (especially C1; a description of what happened) and to a certain extent the intermediate conceptions, especially C4 and, for the year 3/4 children, C5. For the older children, consistency tended to cluster around the use of conceptions C7A, C7B and especially C9. It is clear that a judgment of a child's explanatory performance must include notions of both conception level and consistency.

To look at the interaction between these two factors; sophistication of conceptions, and consistency, I gave each child a score on each of these measures. The **sophistication rating** S_R was generated by scoring their explanations Primitive conceptions (C1 - C3) as 1, Intermediate conceptions (C4 - C6) as 2, and Advanced conceptions (C7 - C10) as 3, and taking the mean score for their five or six explanations.

C_R was calculated as described above. One of the problems that immediately became apparent is the difficulty of deciding just what 'consistent' means. The conceptions C1 to C10 are not necessarily mutually incompatible, so that to use them in parallel does not necessarily denote inconsistency. On the other hand, identical explanations must be counted as more consistent than those which are simply non-incompatible. The conceptions C4 and C4A, conceptions C7, C7A and C7B, and, separately again, C8, C8A and C10 were counted as equivalent, since they involve a similar way of looking at the phenomena. For instance, children who describe the enclosed air pushing on a water surface in one task , then describe the enclosed air sucking or pulling on a surface in another task, are not necessarily being inconsistent. In each case they are applying the same 'mental model' of enclosed air exerting a force on water. In reality, the difference would lie in the fact that the enclosed air pressure is greater than atmospheric in some of these tasks (the 'fountain', and 'blocked funnel') and less in others (the 'sticky dart', the 'upturned glass' etc.).

The judgment as to what is consistent depends to a large extent on one's expectations. For older children, who are coming to grips with the idea of pressure differences across surfaces, or inside and outside containers, 'suction' looks very different to 'pressure', and the use of C8A could be judged as a lapse compared with generally competent use of C10. The more fine-grained the analysis of differences between children becomes, and the more they are expected to be capable of subtle distinctions, the tighter the definition would be on what should be counted as consistent.

Only children who had generated at least five written explanations were analysed in this way. Fig. 1 shows C_R plotted against S_R, for individuals. This graph has been divided into a 4 x 4 grid to represent the number of scatter points in each part of the graph. The superimposed line graph plots the mean value of C_R for each 'sophistication' range. It is clear that, while the sophistication of conceptions is increasing (with age), the 'consistency' follows a definite 'U' curve, a type of graph familiar to readers of the literature in children's science understandings. In this case the reason is clear. The younger children are achieving a high rating by consistently using description as a form of explanation, or by consistently referring to 'the air in the cup' as a generic cause of the different phenomena. As children start to gain more conceptual sophistication and access to more knowledge about air and force and matter, however, they apply these ideas to the different tasks in different ways, thus reducing their consistency. A new idea, then, is first applied to one or two tasks to replace an idea, like 'suction', that had been used consistently. It is not until children have begun to master the more advanced notions, such as 'air pressure' and 'competition for space', so that they can start to apply them consistently across tasks, that the dip in the curve corrects itself.

The bimodal distribution for those operating in the highest sophistication band, evident in Fig. 1, was in fact a direct result of there being two discrete populations operating at this level. The adults account for 5 of the 6 individuals in the high right-hand box, while most of the other numbers in this column represent year 5/6 children. The adults have been excluded from the analysis leading to the line graph, since they represent a rather different population to these primary school children. The resulting 'U' trend is still very clear.

In one sense, the high consistency rating of prep. children is spurious, since they are really using a misinterpretation of the nature of explanation to achieve this consistency. Descriptions of the outcomes of these tasks are not really consistent in any sense of the application of a specific idea across these phenomena. Conceptions 4 (and 4A), involving a non-specific reference to "air inside the glass", are also responsible for high levels of consistency achieved by some children, yet do not necessarily represent the coherent application of a particular view of the tasks except that air is always involved in causing the outcomes. For this reason, I have reanalysed the data to assign a second consistency rating (C_R*)which treats explanations using C1C2, C3, C4 or C4A as non-explanations, and assigns a rating using only those explanations that involve the more specific conceptions C5 - C10. Particularly for the prep children, this means that one is judging their consistency across only 2 or 3 tasks for which they use non-generic conceptions, and this is where the flexibility of the variance as a measure of consistency is invaluable. The mean values of CR* for children at different year levels is shown in Table 3, alongside those of SR and CR.

One can see a steady increase in CR* with age, compared to the U-curve of CR. While this increase is real, the consistency ratings we are talking about are quite low at an absolute level, even for the year 5/6 children. A rating of 1.7, for instance, applies when three different conceptions are used to explain the six tasks. Young children in particular are very opportunistic in applying a range of ideas to different tasks, and do not readily achieve a 'parsimonious' application of ideas they may have mastered across a limited range of phenomena.

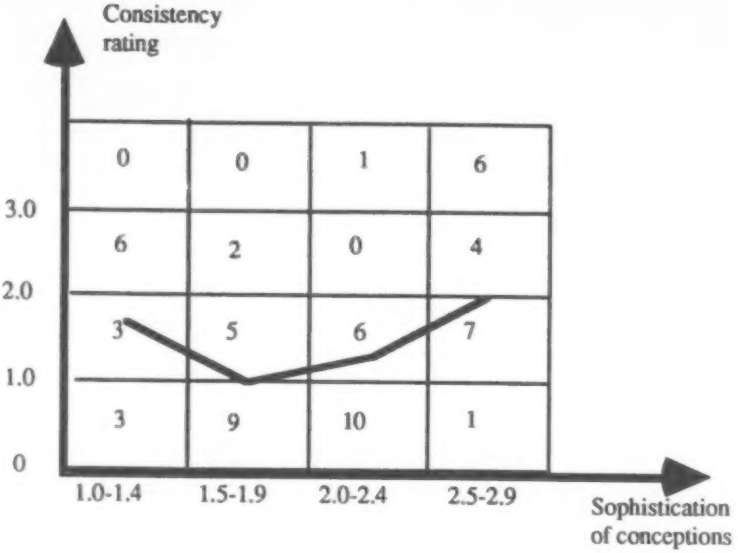

Fig. 3 A plot of consistency vs. sophistication of conceptions

TABLE 3
TRENDS IN SOPHISTICATION AND CONSISTENCY OF CONCEPTIONS WITH AGE

	Number of subjects N	**Sophist. rating S_R**	**Consist. rating C_R**	**Consist. rating C_R^***
Prep. year	18	1.5	1.4	0.6
Year 3/4	18	2.0	1.2	0.9
Year 5/6	20	2.3	1.6	1.7
Adult teachers	7	3.0	3.7	3.7

The variety of conceptions used by children during the activity sessions

Individual children had many opportunities to generate explanations during the sessions, both in writing, in group discussion and sometimes in interview. Table 4 show the range of conceptions used across the tasks by an illustrative subset of Years 3/4 and 5/6 individuals in group discussion and in written explanations. For the purpose of these data, children were credited with using a conception in group discussion if they voiced it themselves or if they actively agreed with its expression by another child.

The table shows clearly the extent to which these children are generating a wide variety of ideas to explain the range of tasks. Very few children at either year level used fewer than five conceptions. Leaving aside C8/10 (action of outside air) which was not used much, each child on average used five of the six conceptions listed in discussing these tasks.

TABLE 4
RANGE OF CONCEPTIONS USED BY CHILDREN

Child	C1-C4	C5	C7	C7A	C7B	C9	C8/10
Year 3/4: SD	4	1	1	1	0	0	1
SJ	6	5	3	2	2	2	0
MK	6	3	1	2	1	7	0
WF	3	2	0	1	2	0	0
Year 5/6: JJ	2	4	2	2	1	6	3
OC	1	7	1	3	1	2	1
AN	2	4	1	2	2	1	0
NF	0	3	1	2	2	4	3

Consistency of use of conceptions in interview 2

The second interview, which took place six months after the activity sessions, afforded an opportunity to look at children's consistency of explanation across the full range of tasks. The results showed a clear distinction between the CR* values for the preps (CR* = 1.6) compared to the older children (CR*=5.4 for the Year 3/4 children, 5.0 for the Year 5/6 children). A close look at the reasons for the reversal between the 3/4 and 5/6 children proved instructive. The year 5/6 children were increasing their use of the notion of external air pressure, thus removing some explanations from a concentration around the 'force of air' notions favoured by the year 3/4 children. The older children also denied themselves access to the 'suction' idea, again reducing the concentration of explanations around the idea of enclosed air exerting a force, and even though they used C9 very effectively, the fact that they retained allegiance to the idea of air pressure (C7B) for a number of tasks 'split their vote', so to speak, and reduced their apparent consistency. The message seems clear; as children develop a wider range of powerful ideas, they learn to apply them only gradually, and their apparent consistency of application suffers a reversal in the short term. In a sense, the more we know, the harder it is to be consistent.

In fact, the older children were actively looking to apply their explanations more widely across contexts. It was apparent during the interviews and the group discussions that the 5/6 children were more interested than the 3/4s, and certainly the preps, to use the same conception (mainly C9) consistently. This observation is consistent with the result on another probe (Tytler, 1993) where the older children were more likely to look for links between tasks based on explanatory principle rather than physical equipment or human factors. These year 5/6 children are actively trying to generate meaning based on physical principle, an understanding of which includes its general applicability across phenomena. The recognition that one powerful explanation is being sought for all these tasks is also a crucial aspect of the achievement of consistency. The drive for consistency of these older children and adults is both a recognition of the power of the generalizable concept, and learning to play the science game.

DISCUSSION

These children have low consistency ratings because they generate a range of interpretive conceptions that they apply in a fluid way across contexts. While the older children are looking to apply their ideas more consistently, they do not do so completely. Even after mastering a generalizable conception as it applies to a subset of the tasks, children hung on to more primitive conceptions to explain others. In the interviews, children who had mastered the notion of atmospheric pressure in some contexts failed to respond to specific prompts to apply the idea more generally. These tasks are all linked by the scientific idea of differential pressure, yet the children do not see them as linked in any consistent way. These children do not operate with a set of beliefs ('alternative frameworks') about the behaviour of air that are applied consistently across a wide range of contexts. Rather, they use conceptions as tools to be applied to contexts, learning to use each conception more competently and expanding its range, before a more powerful and satisfying conception appears in turn and makes inroads into previous explanatory conceptions. Children were working with a range of conceptions which were competing for use, and decisions about which to use seemed to be determined by particular characteristics of the task (physical images that were suggested by the apparatus, metaphorical links, such as notions of 'trappedness' or 'suction', applied to bodies of air, the physical relationships between surfaces and enclosures etc.) and subtleties of application of the different conceptions.

It was clear, both in the analysis of group discussion and in the interviews, that children were applying a range of conceptions even within the same task. Children would refer to the effect of pressure as an adjunct to a 'competition for space' explanation, or to suction and pressure and intentionality of air all within the one discussion. In many cases these multiple explanations represent the intelligent use of conceptions as tools, and in them I can recognize clear echoes of my own views of these phenomena. Since talking with these children I have become aware of the way notions of suction, trappedness and intentionality attributable to air all form part of my conception of these air pressure phenomena. Such notions have a role for the expert as adjuncts, sometimes cues to more complete explanations. The appearance of these notions in everyday language ("suction", "trapped") represents a broader cultural input into the status of these ideas in both novices' and experts' minds.

If it is accepted that our thinking about phenomena is essentially multi-faceted, then the notion of consistency becomes somewhat problematic. The consistent application of a conception across contexts becomes a matter of selecting it from a range of possible others. This will depend on the operation of contextual cues, and on cultural understandings about the appropriateness of a conception in the particular circumstance.

The growth in science understandings is complex, involving increasing domain specific knowledge (Carey, 1985, 1986; Brook & Driver, 1988), understandings about the nature of science explanations (Tytler, 1993), and increasing acceptance of the culture of school science. Formal science knowledge is a different thing to the complex understandings of individual scientists. Even for experts, the achievement of powerful, consistent ideas is only a part of the story of the growth in understanding, for more primitive ideas live on in parallel with these. Conceptual growth proceeds by the acquisition of powerful concepts and by knowing how to use them across an increasing range of contexts, rather than simply by the successive replacement of inferior frameworks with scientific ones. The hallmark of the expert is the ability not only to use all these ideas but also to recognize the situation-specific rules that govern their application, and the interrelationships between them.

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SELF-EFFICACY AND SCIENCE ANXIETY AMONG PRESERVICE PRIMARY TEACHERS: ORIGINS AND REMEDIES

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ABSTRACT

The preservice training of primary teachers is an opportunity to provide positive experiences which may ameliorate students' anxiety about science and science teaching, and enhance their beliefs that they may become effective science teachers. The previous and current science related experiences, and beliefs, of an intake of primary teachers participating in an introductory science content subject, were explored. Matter and energy concepts were major content components of the subject. Data were collected from pre- and post-test administrations of psychometric tests designed to measure students' science teaching self-efficacy, science related attitudes, interest in science teaching, and preferred learning environment. A randomly selected sample of students was interviewed at the commencement and finish of the subject. One third of the sample was assigned to a study group in which a constructivist approach to laboratory sessions was adopted. The remainder of the sample experienced a more traditional transmissive format in laboratory sessions. Analysis of the quantitative data revealed no group differences in self-efficacy. Interesting contrasts between students evident in the data from the interviews facilitated the articulation of tentative assertions about the causative factors that may influence the development of students' sense of self-efficacy and possible science related anxiety.

INTRODUCTION

The attitude of primary teachers towards teaching science is implicitly related to their conceptual understanding of science (Tilgner, 1990; Franz & Enochs, 1982). This perception has been further reinforced through studies which concluded that more emphasis should be placed on preservice primary teachers' knowledge of science concepts (Department of Employment Education and Training, 1989). Indeed, as a consequence of these conclusions, recommendations were made to increase the amount of science content studied by preservice primary teachers. However, this direction needs to be considered cautiously as it does not heed the research on preservice teachers' attitudes towards science and science teaching (Lucas & Dooley, 1982; Ginns & Foster, 1983; Koballa & Crawley, 1985; Schibeci, 1984; Fraser, Tobin & Lacy, 1984). Much of this work identified the cyclical nature of "success following success and failure following failure" and consequent effects on attitudes to and feelings about science.

Germann (1988) proposed a theoretical model that might account for the development of students' poor attitudes to science. Students' fatalism, their perceptions of the value of science, teacher quality, classroom social environment and organisation appeared to be significant factors in contributing to this model. The model, in particular, emphasises the contribution of the teacher to the social interaction and learning environment within the classroom and thus the focal point becomes the teacher-learner-curriculum interaction. The teacher's contribution to the interaction is guided by his or her own world view, attitudes, needs, knowledge and priorities (Clark & Peterson, 1986; Shulman, 1987). Attempts to understand a teacher's ability to cope in such complex interactions, or self-efficacy, have been the objective of research stemming from a social cognitive perspective.

Self-Efficacy

Self-efficacy is one construct emerging from social behaviour research (Bandura, 1977). According to this theory behaviour is based on two factors, firstly, people develop a generalised expectancy about action-outcome contingencies through life experiences, or outcome expectancy and, secondly they develop a more personal belief about their own ability to cope, or self-efficacy. In cases where both self-efficacy and outcome expectancies vary, behaviour can be predicted by considering both factors. For example, Bandura hypothesised that a person rating high on both factors would behave in an assured, confident manner. Bandura's self-efficacy model has provided many significant insights into the general behaviour of teachers (Ashton & Webb, 1986; Dembo & Gibson, 1985; Greenwood, Olejnik & Parkay, 1990).

In examining the domain specific area of science from a self-efficacy framework, Enochs and Riggs (1990) developed and validated the Science Teaching Efficacy Belief Instrument (STEBI-B), containing 23 items for preservice elementary teachers in the United States. The two scales that emerged in STEBI-B were labelled Personal Science Teaching Efficacy (PSTE) and Science Teaching Outcome Expectancy (STOE). STEBI-B has also been validated on a population of Australian preservice primary school teachers (Lucas, Ginns, Tulip & Watters, 1993).

Personal science teaching efficacy is correlated with a student's stated preference to, or not to teach science (Lucas et al., 1993). It is apparent that poor science teaching behaviours may be already established at an early stage in students' preservice careers, thus providing further support for the need to explore the contextual factors that influence student teachers' beliefs about science and science teaching, and related anxiety feelings. One approach to the problem may be founded in Bandura's (1977) argument that performance is the major predictor of self-efficacy, which implies that students who experience successful learning will have positive self-efficacy. From a constructivist epistemology, successful learning occurs in a social and emotional context in which knowledge is constructed cooperatively by learners (Pintrich, Marx & Boyle, 1993).

The purposes of the research were to (1) determine if a relationship exists between commencing preservice teachers' self-efficacy and attitudes to science and science teaching by examining correlations between scores on psychometric tests measuring self-efficacy, science related attitudes and desired learning environment, (2) analyse the changes in self-efficacy beliefs and attitudes of a group of students placed in the context of a laboratory learning environment implemented on constructivist principles, and (3) investigate the effect of prior and current science related experiences on self-efficacy by exploring students' recollections of critical incidents that may have influenced self-efficacy.

METHODS

The design of this study involved the use of qualitative and quantitative approaches. Quantitative data have been obtained through a pretest-posttest design, while rich descriptions of selected participants have been acquired through interview, field notes and observation. The study was implemented during the first semester of 1994.

Subjects

The subjects were students commencing year one of a four year primary teacher education program. At the beginning of the program all 161 students enrolled in an introductory science content subject were randomly assigned to two hour practical laboratory sessions timetabled at regular intervals during the day. Constraints related to room availability and size, timetable realities and assigned staffing limited the extent to which randomised equivalent study groups, associated with two different laboratory learning environments, could be constructed for this research project. Hence, the largest laboratory session quota was subdivided into one study group of 24 students and 48 students in the second study group. Allocation of students to each study group was made on the basis of matched personal science teaching self-efficacy scores obtained in the pretest. Tutor A was in charge of the small study group, and tutors B and C were in charge of the large study group. All enrolled students were required to complete the same subject topics and assessment in accordance with the approved subject outline. Students were required to attend a one hour large group lecture in addition to the two hour practical laboratory sessions each week. A further one hour tutorial was voluntary.

Procedures

Quantitative measures. In Week 1 of the semester all students enrolled in the science content subject were pretested with the following psychometric instruments:

- a measure of sense of self-efficacy - Science Teaching Efficacy Belief Instrument (STEBI-B) (Enochs & Riggs, 1990);
- a measure of the students' desired learning environment - modified Constructivist Learning Environment Survey (CLES) (Taylor, Fraser & White, 1994).
- a measure of science related attitudes - Test of Science Related Attitudes (TOSRA) (Fraser, 1981);
- a measure of interest in science teaching - Subject Preference Inventory (SPI) (Markle, 1978);

The SPI instrument has been validated for use with the level of students being investigated in this study (Lucas et al., 1993). TOSRA measures attitudes to science in seven conceptually different areas and has been validated using high school children (Fraser, 1981). The CLES instrument was modified in the pretest version by rephrasing questions in the future tense as an indication of how students, as tertiary students, would like their class to operate. At the end of the semester all students were posttested using the same forms of the tests.

Qualitative measures. The quantitative measures were complemented by a series of interviews of students in the two study groups. Interviews were semi-structured and undertaken in the second week of semester, and in the last week of semester outside scheduled class times. Forty eight students, 24 from each study group, completed the initial interview. The interviews were designed to encourage students to focus on critical incidents in their life that related to their learning of science either at school during the first interview, and their experiences in relation to the relevant learning environment, or intervention, in the second interview. Research assistants were used to conduct interviews and, where practicable, both pre- and post-interviews were completed by the same assistant. Each interviewer attended a group training and briefing session. Two members of the research team analysed the interviews and alternative interpretations were reconciled by discussion.

Intervention groups. Both study groups were involved in practical laboratory sessions at the same time in two different rooms. Tutor A adopted a constructivist approach to implementing the laboratory session with a focus on identifying students' own prior knowledge and building on naive understandings of concepts taught in the subject (Yager, 1991). Students were actively encouraged to discuss their own interpretations with peers and a journal containing reflective comments and insights was kept by both the students and the tutor. The students were explicitly informed that they were involved in an alternative mode of teaching and learning and how their role as students could be different. The large group laboratory session was presented in a transmissive mode with the tutors presenting a 20-30 minute introduction, followed by a summary of the concepts being studied and laboratory activities being implemented. In order to verify that the characteristics of the two treatments were different and in accord with the design, one researcher attended both sessions on an *ad hoc* basis to observe and note tutor-student interactions and styles of teaching. Furthermore, implementation of the program was discussed during weekly meetings with the tutors and, at the conclusion of the semester, tutors A and C were interviewed and questioned about the philosophy and style of teaching that they adopted.

RESULTS AND DISCUSSION

Analysis of quantitative data

Pre-intervention. Significant correlations between pretest scores on the STEBI-B scales, personal science teaching efficacy (PSTE) and science teaching outcome expectancy (STOE), and scale scores on SPI, TOSRA and CLES are shown in Table 1 for the whole group.

TABLE 1
SIGNIFICANT CORRELATIONS BETWEEN SCORES ON THE PRETEST STEBI-B SCALES, AND SCALE SCORES ON SPI, TOSRA, AND CLES (N =149)

TEST	VARIABLE	PSTE Scale	STOE Scale
SPI	Maths teaching preference	.18 *	
	Science teaching preference	.38 ***	
TOSRA	Social Implications of Science (SIS)		.17 *
	Normality of Scientists (NS)		
	Attitude to Scientific Inquiry (ASI)	.17 *	
	Adoption of Scientific Attitudes (ASA)	.31 ***	.25 **
	Enjoyment of Science (ESL)	.38 ***	.16 *
	Leisure Interest in Science (LIS)	.34 ***	.22 **
	Career Interest in Science (CIS)	.42 ***	
CLES	Personal Relevance of Science (PRS)		
	Scientific Uncertainty Scale (SUS)		
	Critical Voice Scale (CVS)		.18 *
	Shared Control Scale (SCS)		
	Student Negotiation Scale (SNS)		
	Attitude Scale (AS)	.36 ***	.20 *

Note: * $p<.05$; ** $p<.01$; *** $p<.001$

The results confirm the previous findings of Lucas et al. (1993) that PSTE is correlated with a student's preference to teach science. In addition, the personal dimension inherent in PSTE appears to correlate with the more personal involvement elements in TOSRA and CLES, which is similar to the conclusion that traits such as an internal locus of control and self concept relate to a teacher's beliefs about his/her ability to become an effective teacher of science (Lucas et al., 1993). The importance of students' perceptions of empowerment, or control over their own learning in science classroom environments, may be reflected in the correlation between the CLES scale *Critical Voice*, and STOE which embodies a belief that children can learn science given good teaching.

A standard multiple regression analysis was conducted in order to identify the strongest predictors of self-efficacy from the psychometric data. PSTE was set as the dependent variable and scales of SPI, TOSRA and CLES as independent variables which were entered into the equation stepwise. Assumptions of normality of scales were tested by the Lillifors Kolmogorov-Smirnov statistic (Norušis, 1993). *Attitude* (CLES), *Science Teaching Preference* (SPI), and *Career Interest* (TOSRA), contributed significantly to predicting PSTE. In combination, these three variables uniquely contributed to 26% of the variability in PSTE. Thus, those students who initially expressed a positive confidence in their ability to teach science were also interested in science and had expressed a positive attitude towards doing science activities. These students have a strong preference to teach science over other subjects in the primary curriculum. A multiple regression with STOE as dependent variable revealed that *Critical voice* (CLES), *Adoption of Scientific Attitudes* (TOSRA), and *Reading Teaching Preference* (SPI) contributed to only 13% of the variability in STOE. Therefore, STOE is more weakly related to the various scales measured, which might be expected as these scales relate to beliefs about oneself and not other's behaviours.

Intervention effects. Posttest data for the whole group reveal a small positive change in the mean PSTE score, and significant negative changes in the mean STOE score, and a number of mean scale scores on TOSRA and CLES (Table 2). STEBI-B data were also analysed to identify possible intervention effects on each study group. Posttest scores were compared between the two groups using ANCOVA with pretest scores entered as covariates and corrected for differences in cell means. No significant differences were noted at alpha .05.

TABLE 2
PRETEST AND POSTTEST MEAN SCORES ON STEBI, TOSRA AND CLES (N=107)

TEST	SCALE	PRETEST	POSTTEST	DIFF (SD)	SIG
STEBI-B	PSTE	44.86	45.82	0.96 (6.2)	ns
	STOE	35.23	34.40	-0.83 (4.2)	<.05
TOSRA	SIS	36.49	35.28	-1.21 (4.2)	<.01
	NS	35.17	36.08	0.92 (4.3)	<.05
	ASI	37.48	35.43	-2.05 (6.2)	<.001
	ASA	38.30	36.45	-1.85 (4.1)	<.001
	ESL	32.29	32.11	-0.18 (5.9)	ns
	LIS	27.02	26.15	-0.87 (5.6)	ns
	CIS	28.41	27.87	-0.54 (5.9)	ns
CLES	PRS	23.68	20.74	-2.94 (3.0)	<.001
	SUS	22.21	20.72	-1.49 (2.5)	<.001
	CVS	22.81	21.36	-1.45 (3.5)	<.001
	SCS	18.89	15.11	-3.78 (4.6)	<.001
	SNS	23.74	21.63	-2.11 (3.3)	<.001
	AS	22.73	19.93	-2.80 (3.4)	<.001

Multiple regressions were repeated with the posttest PSTE as described for the pretest. Thirty three percent of the variability of PSTE was accounted for by the combined scale scores on *Social Implications of Science* (TOSRA), and *Attitude scale* (CLES). Attitude, a scale which captures a feeling of enjoyment with classroom activities was a significant contributor to PSTE at both stages of testing. Social implications of the role of science now contributes more of the variance in PSTE suggesting possibly a more critical view of science which may reflect students' understanding or awareness of issues raised as content in the subject. Only 22% variability in STOE posttest scores was accounted for by any of the variables. These included significant contributions from *Personal Relevance of Science* (CLES) and *Social Implications of Science* (TOSRA).

Case by case analysis of the two study groups indicated that the personal science teaching efficacy of a number of students in the two study groups changed by more than one standard deviation during the semester. It is clear that more complex information is being overlooked by relying solely on the analysis of evidence from psychometric tests, hence there is a need to examine the qualitative data from the interviews. These data are discussed in the following section.

Analysis of qualitative data

Observations of the two intervention groups indicated that changes in styles of teaching occurred during the semester. These observations were supported by comments made during the interviews with the tutors. Tutor A, while implementing strategies that were consistent with a constructivist epistemology, recognised that external constraints such as evaluation were issues of constant concern to the students. Students' negative reactions to the rigid structure of the transmissive mode of learning in the laboratory sessions run by Tutors B and C resulted in the renegotiation of some operational structures that gave greater opportunity for interactive questioning. Environmental factors concerning personalisation and power for the latter group were not observed to change.

Students' reflections on their previous and current science related experiences were probed in a semi-structured format during the two interviews. Interpretation of the interviews will be presented and discussed as a series of tentative assertions.

Assertion 1: Experiences in school are related to low or high self efficacy. The most powerful recollection held by students and expressed during their first interview concerned the quality of teaching at high school. Comments by students who had PSTE scores in excess of 50 all reflected well on teachers.

One of the students, Harriet, believed that good teachers were helpful and explained things effectively while Adele recalled: "Yes, I did biology which I liked and found very interesting because it had things to do with the body and environment and it was easier to learn. My high school teachers were approachable and good and they encouraged me". Tammy, a mature age student, liked Grade 11 biology because of the ways the teacher taught the class and the study groups that were developed. Another student described herself as being very interested in science especially where it related to real life and she found her "teachers originally good". The characteristics of good teachers appeared to include the ability to make science interesting and fun. Good teachers also were helpful, approachable and established good classroom environments. Primary teachers were clearly more endearing than secondary.

In contrast, comments from students with PSTE scores below 35 covered a range of negative recollections, including ones of personal animosity. Bernadette hated secondary science and only did it for a university entrance score: "teachers were aiming at a level too high for her". Bunny described "horrible teachers which used to yell at students". Other recollections included negative feelings about the absence of a link between the schoolwork and real life, and the teacher being sarcastic and derogatory.

Assertion 2: Science experiences for positive self-efficacy changes should be fun. During the first interview 14 of the 48 students expressed a positive attitude to science. The majority of these 14 linked their feelings to interest in activities, excitement, and practical or hands-on work. A minority spoke in terms of a quest for knowledge and a need to understand science for social ramifications. The predominant reasons for not liking science related to modes of learning including too much writing, no discussion, too theoretical, boring and irrelevant content material.

Blumenfeld-Jones (1994) asserts that pleasure may be a central category of belief to which educational beliefs may be connected. Students in the laboratory sessions taught by A had the opportunity for public discovery and exploration of concepts and sharing those discoveries with peers in a 'marketplace of ideas'. Several students described experiences that they framed in a context of fun. For example, Michelle considered whole group lectures as boring but laboratory experiences with A were fun and motivating: "Lectures were boring but my views changed when I went into A's group. Laboratory was great fun and it made you interested. If you are not interested in the subject you won't listen". Adele shared similar impressions. In her first interview, she expressed sentiments that have been observed in the majority of preservice teachers interviewed for this study:

> Science to me is learning things in parrot fashion. It's all about writing things out and trying to remember them. That is a bad way of thinking but it is what happened at high school where we were told to do that as the only way of getting through. I wish there was another way and that you could enjoy science and understand science without writing hundreds of times. I really hate sitting at home trying to learn something by heart.

Subsequently she reflected: "Our lectures were initially daunting because a lot of information was just spat at you but now I am used to it. ... Now I do (understand) and therefore I enjoy it. A's group was fantastic." Adele's PSTE score regressed from 52 to 46 but the final score was still above the mean. No student in his or her post-interview described B's laboratory session in terms of fun or enjoyment.

Assertion 3: Opportunity for discussion and interaction promoted the maintenance or improvement of self efficacy and provided an environment where risk taking was encouraged. Debby was pleased with the "alternative, laid back, informal approach" of A's group. A key element of this informality was the opportunity to discuss and talk about science. Lesley, a mature age student made a point that underpinned her concern about science in her first interview and reinforced the same idea 14 weeks later. Before classes began she described her apprehension about science. This apprehension was also evident in a low PSTE score of 31.

> My reaction to science is a mixture between fear and a desire to overcome that fear. I want to ask questions, but not feel foolish. I don't feel competent at teaching science because I don't understand it. I have a desire to find out but I cannot learn things by rote, I must understand. I think I am the one who will lose out if I don't ask questions.

Subsequently, Lesley acknowledged her earlier anxiety, but was adamant that her feelings had changed because: "the workshops have changed my attitudes. Journal writings in A's workshop helped ... I wanted to talk about science which we were able to do in tutorials". Lesley's PSTE score meanwhile increased from 31 to 53.

Opportunities for discussion were raised by students in B's laboratory session but in terms of being able to work together in groups. Thus, the possibility for debate and negotiation of meaning between students themselves did exist and was not practised. In some respects students were forced to be more autonomous and to clarify their misunderstandings in order to raise questions. Angie described her experiences: "A lot of experiments that we did were not defined. We were left by ourselves. They did not turn out because we did not know how to do them. We had to watch some one else's group". Although Bunny held similar ideas and "never knew why we were doing the experiment" her PSTE increased from 30 to 51.

Assertion 4: Students are driven by internal and external motivation.

Some students in A's group expressed concern about the operation of the group. The issue not only surfaced in the interviews with the students but was discussed in the laboratory sessions and was of constant concern to A. The new approach was time consuming and it was felt that concepts could not be dealt with in sufficient depth. As tutor A noted in the interview:

> I think there was that worry about the exam, and I think that if we'd been able to come full circle on each major concept, that may have had more impact, because they would have then felt confident about what the scientific...they would have understood the scientific idea, and perhaps felt more confident about things.

Victoria, for example, did not like the informality of A's group and described the journal writing unfavourably: "I used to write proper structured experiments which was more useful than trying to write up feelings". Her PSTE fell from 44 to 40. Bunny, a student in B's study group, was overawed by B but realised that the tutor "expected very high standards" which she was able to achieve in the form of a final grade of 7 in the subject.

CONCLUSIONS

This study showed that prior experiences related to the learning and teaching of science may influence beliefs about one's ability to teach science operationalised as Personal Science Teaching Self Efficacy. Key findings include the role of preservice teachers' recollections of the behaviours and attitudes of their own teachers as a factor in developing positive teaching self-efficacy. Quality of teaching has been identified in previous work by Haladyna, Olsen and Shaughnessy (1983) as an important factor in developing attitudes. The observations reported here extend the influence of teachers to the development of self-efficacy and confidence. Having experienced good teachers is conducive to becoming a self-efficacious teacher oneself.

In an associated study (Watters & Ginns, 1994), PSTE was found to be related to an academic self concept measure described as *identification versus alienation* which is a scale that measures a student's feeling that teachers care about their students (Michael & Smith, 1976). The structure and implementation of A's laboratory sessions encouraged most students to participate in discussion and to air their problems. The environment was supportive and caring and the tutor provided a role model that should enhance PSTE. However, some students expressed concern that they would not get enough information in that environment and, therefore, were not likely to pass the final examination. Although only a minority of students expressed this view the feeling may have been more widespread and not detected. The feelings of empowerment and control over their own learning experienced by students in a constructivist learning environment may have been balanced by concerns and anxiety related to assessment procedures in the subject. The absence of any significant differences between the treatment groups based on an analysis of PSTE scores tentatively supports this contention. It is of some concern that the implementation of a constructivist based teaching intervention was not overtly successful. A transition into such an environment from what would have been a more traditional environment for most participants was problematical. Given the course structure, the laboratory sessions were only one component and broader university and course issues may have dominated beliefs and attitudes.

The fall in mean STOE scores during the semester is explained by the absence of experiences in the science content subject which allow students to observe children learning science. Ginns & Watters (1994) noted that preservice students' outcome expectancy increases during a science methods subject that involves practical science teaching experiences with children. Observation of the successful impact of science teaching on children appears to be a necessary component for a positive change in STOE.

In accord with our other studies (Ginns & Watters, 1994), these results confirm the suggestions of Ashton and Webb (1986) that self-efficacy may fluctuate during the course of a teacher education program perhaps varying as students experience difficulties or success with various facets of a preservice teacher education program. The findings affirm the conclusion that there is a continuous need to monitor preservice teacher's sense of science teaching self-efficacy and consequent development of attitudes to science and science teaching in order to inform the practice of teacher educators. There is also a need to monitor the changes in self-efficacy as teachers are inducted and socialised into the teaching profession.

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TEACHER PROFESSIONAL DEVELOPMENT: WHICH ASPECTS OF INSERVICE DO TEACHERS BELIEVE INFLUENCE THEIR CLASSROOM PRACTICE?

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ABSTRACT

Research into teacher inservice in primary science generally focuses on evaluating the objectives of each program in terms of the immediate outcomes. Little research appears to have been conducted into the long term effects of interactive inservice programs on the classroom practice of the participants. During 1993 the long term effects of participation in the Primary Science/Technology Project (Sci-Tec), as perceived by the teacher participants, were investigated. Focus teachers who had participated in Sci-Tec between 1988-1991 were asked to provide information about their current science teaching practice, and about the influence that Sci-Tec had had on their current practice. Six of these teachers were then interviewed to determine which specific aspects of the project they believed had most influenced the development of their current classroom practice in teaching science.

INTRODUCTION

Research into teacher professional development in science has been conducted in the United Kingdom (Driver & Oldham, 1986; Johnston, 1987), New Zealand (Bell, Kirkwood & Pearson, 1990; Bell, 1993), and Australia (Aubusson, Relich & Wotherspoon, 1991; Crawford & Zeegers, 1993). Findings indicate that an interactive approach to inservice which is based on a constructivist view of learning has proved successful. Such an approach values the knowledge and experiences of the participants and incorporates them into the program. While several programs have acknowledged that these elements are important, there are few which have attempted to implement such an approach as their basic principle and little research has been conducted into the outcomes of these programs. Two models which have recently been documented are the English model, known as the 'Cascade model' and the interactive model from New Zealand. The former, according to the Department of Education and Science Report (1990-91), has had limited success in influencing science education in schools. The outcomes of the interactive Learning In Science Project (Teacher Development) indicated positive teacher responses to the constructivist based inservice program (Bell, 1993).

Of the more successful professional development programs which have been evaluated, a number of common elements have been identified. The Australian Language and Learning Project (Scarino & Vale, 1988), Baird (1988), Fensham (1988, 1990), Hardy, Bearlin and Kirkwood (1990) and Osborne (1982) each mention the necessity of allowing time for the participants to meet, time to reflect on their own beliefs about teaching and learning and time to develop their confidence in teaching science. Louden and Wallace (1990) discuss the necessity of considering the biography of each teacher in order to effect change. Aubusson, Relich and Wotherspoon (1991) argue that there are differing needs amongst teachers depending on the length of time they have been teaching and therefore professional development programs which differ in their foci need to be provided for the teachers. Bell and Gilbert (1993) also take up this issue in recommending that professional development programs address three aspects of teacher development, which are interrelated - the professional, the personal and the social aspects.

BACKGROUND TO THE RESEARCH

The Primary Science/Technology (Sci-Tec) Project was a cooperative venture between the S.A. Education Department and the former S.A. College of Advanced Education (now the University of S.A.) between 1988 and 1991. The project had three phases. During phase one the 'focus teachers' developed their own classroom practice in teaching science, they then assisted teachers within their own schools to develop their classroom practice. In phases two and three of the project the focus teachers worked with pairs of teachers from neighbouring schools. They assisted them firstly to develop their own classroom practice and secondly to develop the skills to inservice teachers within their schools.

Three unpublished reports on the Sci-Tec Project have been prepared, one by M. King of the University of New England in 1988, and the others by the author together with G. Crawford in 1990 and 1992. These reports identified key principles on which the project was based:

* the sharing of the expertise within the group
* the necessity of developing a shared ownership of the project by all of those involved
* the importance of responding to needs
* the establishment of support networks.

The project did not attempt to pre-determine what the major outcomes of implementing these principles would be, rather that as the project developed and as teachers identified their needs and concerns in relation to their science teaching, these major outcomes would emerge.

Major outcomes of the project in 1991 were identified in the reports written by the focus teachers for the final Sci-Tec Report (1992). These were:

* having time to reflact, to plan, to organize and to provide inservice for others
* the development of networks both within schools and across schools
* the development of teaching methods
* personal gains in status, confidence and self esteem
* improved interpersonal skills with other adults

It is now three years since the inservice component of the Sci-Tec Project ended. The opportunity for reflection has raised a number of questions about the long term outcomes of the project:

* What is the current status of science teaching in the classrooms of the original focus teachers?
* Do the focus teachers believe that the project has influenced their current practice?
* What aspects of the project would the teachers link to their current practice?

This research project identified which aspects of the Sci-Tec Project the focus teachers believed had most influence in developing their current classroom practice in science.

METHOD

Informants

The informants were the 37 original 'focus teachers' who, at the time of the Sci-Tec Project, had been teaching in Years 5 to 7 in S.A. Education Department schools. The teachers were located in 24 'focus' schools throughout South Australia, ranging from Roxby Downs in the north to Mount Burr in the south, and from Port Lincoln in the west to Berri in the east. These teachers had been Sci-Tec 'focus teachers' for a minimum of two years of the three year term of the project. They had had a responsibility for primary science inservice within their own school and with key teachers from 5-10 local schools during the three year period. Of the 37 teachers, 26 responded to the request for information about their current classroom practice in science.

Instrumentation

The principal methods of data collection were questionnaire and interview. The combination of these two methods means that there were elements of both quantitative and qualitative data presented in the research findings however qualitative data dominated.

Procedure

Prior to the collection of the questionnaire data, each of the 37 focus teachers was sent a letter outlining the research project, its aims and its requirements. As participants the focus teachers were advised that they would be asked to reflect on their current science teaching practice, to analyse it, and to explain it in relation to their participation in the Sci-Tec Project.

The teachers were invited but not pressed to participate. They were assured that the information they provided would be kept confidential and that the final draft of the research would be available for their responses. Those teachers who completed the questionnaire were asked to indicate whether they would also participate in an interview about their classroom practice.

The questionnaire

The purpose of the questionnaire was two fold. Firstly it was used to establish what the current science teaching practice of each teacher was and to determine how her/his science teaching practice had been influenced by the project. The second focus of the questionnaire was to identify a group of teachers who gave responses which were representative of the group and who could be interviewed about the influence of the Sci-Tec Project on their current science teaching practice.

The questionnaire sought information from teachers about their

* level of participation in the project (Q. 1,2,3,4)
* planning and programming of science (Q. 5,6,7,8,9)
* perceptions of their own development in teaching science (Q. 10,11,12,13)
* beliefs about the influence of the project on current science teaching practice (Q. 10,11,12,13)

The data were initially coded on the basis of the first ten questionnaires returned. These codes were reviewed and modified when all of the returns had been received. A frequency tally of responses was made per question and the data were entered on a data base. Once the database had been established, common responses were identified.

Analysis of the questionnaire data

Because of the open ended nature of the questions, the teachers' responses were quite varied. There were however six key elements relating to the development of the teachers practices which were identified. These were that participation in the Sci-Tec Project had resulted in focus teachers:

* having an increased awareness of the how children learn best and how to cater for this
* using an integrated approach to planning science activities,
* having an increased awareness of the resources available for science
* having increased confidence in teaching science
* developing a variety of skills and methods in teaching science.
* incorporating an investigative/hands on approach to teaching science

The specific identification of at least three of these key elements in a teacher's questionnaire was used as one of the criteria in the selection of teachers for interview.

Selection of Interviewees

Six criteria were developed to select the teachers for interview. The net result of the selection process was that seven of the focus teachers were selected for interview. These teachers were willing to be interviewed, they believed that their practice had been positively influenced by the Sci-Tec Project, science played a key role in their classroom program, their responses mentioned at least three key elements, they lived within a 50 km proximity of the city of Adelaide and they were classroom based teachers in 1993. An eighth teacher, who had initially declined to be interviewed, was also approached for interview because of the large number of key element responses she had made in her questionnaire. She agreed to be interviewed. In all, six of the eight teachers agreed to be interviewed, four females and two males. The other two teachers were on leave during 1993.

The interviews

The interview questions were structured to enable the teachers to

- verify my interpretation of the information they had provided in the questionnaire
- elaborate on any points that needed further information
- respond to my interpretation of what the key elements were and relate them to their current practice
- relate their responses about their current practices to past events in the Sci-Tec Project.

Although structured questions were asked there was some flexibility in the orchestration of the interview. The order of the questions was changed where appropriate, to accommodate particular responses or lines of thinking by the teacher. The interview structure also enabled supplementary questions to be asked.

Each of the six teachers participated in one 50 minute structured interview, at a time and location negotiated with the interviewees. The interview questions had been sent to the teachers prior to the interview, firstly to indicate the format and content of the interview and secondly to enable them to begin reflecting on their practice in preparation for their interview responses. An accompanying letter suggested ways which might help them to do this.

Analysis of the interview data

The interviews were audio taped and field notes were taken. Following the interviews, respondent validation of each of the interview transcripts was carried out by sending each teacher a verbatim copy of her/his interview transcript. The interviewees were asked to respond to their transcript, making whatever amendments they believed would give a more correct picture of their views.

The interview transcripts were analysed individually. Every point made by the interviewee was recorded, question by question. Following each individual analysis, common responses were identified. Although the responses were individual by nature, trends emerged when the data was compared.

FINDINGS

From the analysis of the interview data it appeared that the teachers were clearly able to articulate how their practice had changed, however they were less specific when trying to identify particular aspects of the project which brought about these changes. Statements such as "It was because of the nature of the program", "It was the whole general approach" and "It was all so interrelated", indicated that there was no one specific session or event which they could identify as the major influence on their practice. Points which were emphasised however were in relation to the revisiting of principle ideas throughout the project, the constant use of and referral to appropriate resources, the reinforcing of concepts through activities, and the opportunities for reflection about how to apply the strategies and ideas to their own classroom practice.

What is indicated by this lack of commonality in identifying specific aspects of the project which have affected their current practice is the finding that Sci-Tec provided different things for different people. The participants selected what was appropriate for their situation and adapted it to suit. Despite this individuality there are some key ideas about the project's influence on the current classroom practice of the focus teachers which can be drawn from the data. These key ideas are interrelated and so extracting each one still leaves a degree of overlap with others.

The development of practice. It was clear that each of the teachers believed that their practice had been profoundly influenced by their participation in the project. Each made statements such as "It was my personal development which influenced my professional development in my teaching approach. I think that was the linchpin in the whole thing", and "[I was] not expecting us to be at any level but really working from where we were at by setting it up and allowing us to do science and learn something along the way and I just took all that back and developed it."

Being made aware of and being able to use different teaching approaches is a strongly made point. Even the teachers who had taught science prior to their participation in the project very clearly identified the influence of the project on their practice, mentioning changes in method to include an interactive or a hands-on approach, considering children's previous experiences and concept development, and being able to adapt and develop ideas with less reliance on published resources.

The development of support networks. Equally important were the teachers' beliefs that developing a support network did and still does influence their teaching practices. Four of the six teachers specifically mentioned former project people with whom they still network and that this networking now extends beyond science teaching.

Specific project support networks which were referred to included the focus teacher area meetings, the inter school phase 2 and 3 teacher meetings, and the support of the project team itself. The support obtained from these groups of people came in a variety of forms and included showing new resources or activities, sharing experiences and ideas, seeking or providing assistance with ideas or strategies and the cooperative planning and running of inservice sessions.

The use of resources. Science is still perceived as a heavily resource based subject. An issue for many teachers is the apparent lack of resources in schools. What the interviewees were keen to report was that they had found that science could be done without expensive 'science' equipment. The use of consumables and junk materials had become a major feature of their science programs.

Tied in with this change of attitude about resources was the teachers' stated confidence in their ability to refine, adapt and develop ideas and resources to suit the needs of their students and themselves. Once the teachers had become familiar with what resources were available, they became adept at incorporating them into their programs and in some cases rejecting the need altogether for published written resources.

Increased confidence in teaching science. The frequent mention of the growth in confidence to teach science has to be regarded as one of the prime factors which has led to the continuation of science being taught in the classrooms of the interviewed teachers.

The teachers referred to their increased use of and organization of resources, their confidence in teaching in a more investigative way and in sharing information with other people. Two teachers believed they had won high profile school based positions because of their increased confidence through participating in the project.

The integration of science with other subjects. Using an integrated approach was the favoured way of programming science activities in the classroom curriculum. The integration of science with other subjects varied from teacher to teacher and even within each teacher's program. Some themes were developed from a science based topic, others incorporated science into the theme. The integration of science was favoured because it was seen as both a means of emphasising the relevance of science to the students through a cross curricula approach and as a time management strategy for a busy classroom.

Major aspects of the Sci-Tec Project

Analysis of the data from the interviews with the six focus teachers has identified three major aspects of the Sci-Tec Project which have most influenced the focus teachers' current classroom practice in teaching science. These are:

- the ethos of the project
- the inservice program at the Underdale Campus
- the development of support networks.

The ethos of the project. According to the interviewees, the interrelationship of the many aspects of the project created a project ethos which all of the participants felt. The spirit of the project was difficult for the teachers to enunciate, however they provided examples such as:

- the regular revisiting (spiral nature) of major concepts such as the development of children's concepts in science
- the relaxed nature of the project throughout which the elements of enjoyment and fun were incorporated
- the role modelling which was done, initially by the project team and then by the teachers themselves
- being constantly involved in using equipment and conducting investigations
- the emphasis on sharing and collaboration by all participants.

The inservice program at the Underdale Campus. There was a unanimous response from the interviewees that it was the initial two week inservice program at Underdale which set the scene for the project and caught the teachers up in the spirit of it. They referred to the many and varied sessions in which they were involved as well as the time made available for reading and reflection. They discussed how they were given opportunities to try out ideas which they had not encountered previously or had avoided until then. The focus teachers talked about how they had developed skills in new areas, the comradeship which was fostered, and the emphasis on modifying and applying the program's practices to suit their individual classroom situations.

The development of support networks. The first support networks were developed during the initial two week inservice program at Underdale. These networks developed between the focus teachers themselves and with the project team. The networks then developed into strong district support teams. These were further developed and extended as the teachers began working with other teachers from phase 1, 2 and 3 schools. A common element identified in each of these support networks was the sharing of experiences, the exchange of ideas and the friendships which developed.

DISCUSSION

Further analysis of the interview data indicates that the development of the support networks was the most significant aspect of the Sci-Tec Project's influence on the development of the focus teachers' current classroom practice in teaching science. The frequency of its reference and the fervour with which it was discussed by the focus teachers renders it a significant aspect of the Sci-Tec Project. Extending from this finding is my belief that having a network of support has led to an increase in the teachers' levels of confidence in teaching science and this in turn has positively influenced their teaching practices.

These research findings support those of the Learning In Science Project (Teacher Development), which reported on the importance of factors such as teachers talking to other teachers and sharing anecdotes, teachers contributing to the program and the importance of ensuring that the program has a focus on teaching methods (Bell, 1993).

Implications for teachers and researchers

Insights from the research raise a number of issues about the development of primary teachers' practices in teaching science. If it is accepted that establishing support networks is an important step in the development of teachers' practices in teaching science, then inservice providers and teachers need to determine how effective support networks can best be fostered. Time and opportunity are two of the aspects identified during the research.

Other implications which arise from this research study are the necessity of developing inservice programs which:

- value the expertise the teachers already have
- enable teachers to reflect on their beliefs and practices
- allow for individual needs to be catered for
- help teachers plan coherent programs of science rather than single activities
- assist the teachers to become independent of external inservice providers.

The issues raised are fundamental to the development of inservice programs which aim for long term changes in practice and improved outcomes for both teachers and students. Attaining such goals necessitates a collaborative approach which seeks, values and responds to the input of every participant.

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Research in Science Education, 1994, 24, 366-367

ABSTRACTS AND RESEARCH NOTES

THE STRATEGIC TEACHING FRAMEWORK: THE USE OF MULTIMEDIA IN TEACHER EDUCATION

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RESEARCH NOTE

Multimedia in teacher education

A major concern of teacher educators is to provide student teachers with teaching experiences and to encourage them to teach thoughtfully and to reflect upon the consequences of their teaching practices. Ideally, students should experience different classroom practices, different teachers and classrooms. These ideals are difficult to reach in the face of limited budgets for school experience visits. Time constraints on the supervising classroom teacher can limit the amount of time spent in reflection with the student. It was with these concerns in mind and a consideration of the characteristics of teaching that members of the Centre for Research into Educational Applications of Multimedia (CREAM) began to develop a hypermedia learning system based on the Strategic Teaching Framework.

Titled *Teaching in Context*, the STF is a multimedia program integrating video coverage of an exemplary teacher covering an integrated Science and Technology unit, audio commentary, and a data base of relevant theoretical concepts which are exemplified on the video or discussed in the audio comments. The concept is based on the Strategic Teaching Framework (STF) which was developed by Indiana University together with the Central Regional Educational Laboratory in the U.S.A. (Fishman & Duffy, 1992)

The STF relies heavily on video footage of the classroom under study. The video shows an integrated program at work in a 'family group' class. The model of this STF is that of a student being apprenticed to a teacher. The mentor teacher models the teaching behaviours for the student user of the system AND reflects on their own behaviour. The mentor teacher provides a model not for the purpose of being imitated, but to provide a basis for the student to analyse the instructional strategies. Included in the STF is a 'forum' feature. Users can contribute to the STF by typing in their thoughts as they work through the hypercard stack. Students can read what others have written, return and examine their own thoughts when having first viewed the STF. At any time during the viewing of the Quicktime movie of the classroom, the student may listen to the mentor teacher speak about what is going on, listen a selection of experts as they give their points of view when observing the class, search the database for information relevant to the particular segment being viewed or read or insert forum comments.

Students can watch the classroom in operation as a whole; and/or focus on the various themes which can be followed through the video clips and data base. Themes such as teaching strategies, classroom management, cooperative learning, activities, etc. Progress through the STF becomes the student's personal journey; the learner has direct control of the display of video, audio, data base, etc., increasing student ownership for the process of learning and supporting the learner's focus (goals). Because of this, it is essential in creating a resource as information-rich as the STF that students can 'navigate' easily and find the information they need quickly. This was a prime consideration in the organisation and layout of the STF.

Organisation

The unit covered in the STF is broken down into segments corresponding to lessons or parts of lessons during the unit. These lessons are accessed through a system of hierarchical menus. The student can proceed through these segments sequentially or focus on selected segments. The student may also view the unit by following selected themes through the STF. At all times from any card in the stack, the student may access the lesson overview, student forum, data base, teacher's comments and expert teachers and researchers comments, or return to the lesson or theme menus.

Conclusion

Teaching needs to be studied in context, as a whole. This approach would require the student to spend much time in classrooms and in reflection. The STF is a learning environment which while not replacing actual teaching experience, can support that experience and allow students to maximise the benefit of the time they do have in the classroom. Students can learn about instructional strategies in a classroom context, tapping into an experienced teacher's knowledge and experience. The motivation for creating the STF was not to 'teach' the students the 'correct' strategies to use in the classroom, but to support them in constructing and testing their own understanding of the instructional strategies in a classroom context.

The next phase of the project will be trials of the STF with pre-service primary teaching students. A copy of the prototype will be installed at Newling Primary School so that the teachers there can become familiar with the project and offer comment. After this exposure to the concept, a survey will be conducted to determine the structure and content of an STF which would support in-service training.

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DETERMINANTS OF THE COMPETENCE AND CONFIDENCE OF TEACHER EDUCATION STUDENTS STUDYING PRIMARY SCIENCE EDUCATION

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RESEARCH NOTE

This study investigated the views of primary teacher education about their secondary science experiences and science and science education generally. The students were all beginning certain science education units. It was considered that the perceptions students have at this stage could contribute to their success (or lack of success) in the science education units and in their implementation of school science in later years. The sample consisted of 148 students of whom 108 were female. Most students had taken some science through secondary school and a few had taken some post-secondary science. The questionnaire used contained items covering secondary experiences, interest in science, views about scientists or science, and views about primary science education. The students were also asked about their expectations of the unit which they were about to take.

RESULTS

Secondary science experiences

Most students reported either no change, or an increase in, interest in science during secondary studies. They were most interested in biology and environmental science and least interested in physics and chemistry. Most could remember some topics in a positive way and these topics were often from biology (particularly genetics), environmental science and astronomy. About one-third of the students remembered at least one science teacher considered to be 'excellent' and most considered their teachers to be adequate. About one-half of the sample had taken Biology in year 12 and one-quarter had taken Chemistry.
Other subjects were taken in smaller proportions (probably because of low interest and variations in school offerings).

Views about science and scientists

The wider interest in science reported appeared to quite high (mean 6.8 on a scale from 0 to 10) and students indicated strong agreement with the proposition that science is important for world progress. There was more diversity of views about the value of science in controlling word population and about the complexity of science language. Some stereotypical views of scientists were evident (maleness, eccentricity, traditional equipment and clothing) but many students (at least 40) saw scientists as normal people (few knew a scientist personally). Some students noted that the questions about scientists encouraged stereotypical responses. This suggests a heightened awareness of the dangers of stereotyping.

Views about primary science

There was a strong view that science ought to be taught in primary schools (147 of the respondents believed this) and that science is important (mean value 8.6 on a scale from 0 to 10). Females supported this view even more strongly than males (difference significant at the 0.004 probability level).

The students were able to suggest several topics that they considered children would like to learn. About 64% chose at least one topic that could be considered to be environmental in content and 40% mentioned at least one biological topic. Other topics mentioned covered a wide range but physical science content was relatively uncommon (mentioned by 20%).
When asked about the likely enjoyment of children in learning about chemistry, physics biology, earth science, environmental science and technology it was notable that the mean estimates given by respondents were quite uniform and high (6.5 - 7.6 on a scale from 0 to 10). These estimates did not correspond with the students' reports of their own interests. There was also a belief that 'mixed' activities would be very enjoyable as would learning about things noticed in children's lives outside school. Females were more positive than males in predicting enjoyment in all of these topics and some differences were statistically significant at the 0.05 level.

The respondents generally did not accept that males learn science better than females or that experiments or activities are too messy or that doing science is dangerous. While it was evident that most of them did not want to become specialist science teachers, it was clear that almost all were favourably disposed towards science teaching and this view was stronger than the authors might have expected.

Expectations of the unit about to be taken

The students from whom these views were sought were undertaking a variety of science or science education units and there was a range of expectations consistent with this. However the largest group of expectations were concerned with 'How to teach primary science' (28%) and others were related to environmental topics (24%), biological topics (25%), physical or earth science topics (13%). A number of students (13%) expected to improve their basic science knowledge and some also mentioned interest rejuvenation.

Conclusion

This study suggests that most students entering science or science education units in pre-service primary teacher education courses have a positive attitude to the teaching/learning of primary science and see value in all domains of science for children at this stage. This was an unexpected finding. It was of concern however, that their interest in physical science topics was so low. This may be due to previous specific experiences in secondary science. Science and science education units should build on the positive attitudes of students and could develop physical science ideas through their significance in environmental and social problems.

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Research in Science Education, 1994, 24, 370

PERSONAL CONSTRUCT PSYCHOLOGY AS A CONSTRUCTIVIST APPROACH TO LEARNING

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ABSTRACT

This paper proposes that Kelly's Personal Construct Psychology deserves examination as a constructivist basis for science teaching and learning. It argues that because of the explicit nature of the psychology, the clear definition of learning and meaning and the integration of affective, psychomotor and cognitive dimensions of learning, the psychology has much to offer science education.

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DETERMINING YOUNG ABORIGINAL CHILDREN'S SCIENTIFIC UNDERSTANDINGS: A PILOT STUDY

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RESEARCH NOTE

Research into Aboriginal science, has questioned the Western orientation presently accepted as the norm in science research (Watson & Chambers, 1989) and curriculum development (Christie, 1991; Ritchie & Kane, 1990) and begins to explore how scientific knowledge is constructed in Aboriginal communities. However, most of the literature available is predominantly anecdotal (ERIC search, 1985-1993).

With the release of the National Curriculum Statements and Profiles more needs to be understood about the cross-cultural nature of young Aboriginal children's scientific understandings. Consequently, it was decided to develop a pilot study which would systematically examine the overall design, and closely scrutinise the instruments developed for their ability to research young Aboriginal children's understandings in science.

DEVELOPING THE RESEARCH INSTRUMENTS

The study focused upon 10 four and five year olds in a preschool context and 15 six to eight year olds in a school context. It was decided to concentrate only upon rural Aboriginal children. The specific areas investigated included:

- the sun and its place in the solar system - under the strand of *Earth and Space*.
- materials: their properties and uses - under the strand of *Natural and Processed Materials;*
- light - under the strand of *Energy and Change*; and
- intuitive taxonomies of their living environment - under the strand of *Life and Living*.

Cross-cultural factors were considered in the development and use of research instruments.

Day and Night: *Earth and Space*

Since the sample of young Aboriginal children was drawn from country preschools and schools, an artificial environment had to be created. It was decided to set up an area within the school or preschool that could be darkened, so as to simulate night. Black plastic with luminous stars in the configuration of the night sky was hung above the heads of the interviewer and interviewee in the darkened room. As part of this context, a campfire scene was simulated. Within this context a story about night and day, involving a family going camping in the bush was read to the children. This was followed by the opportunity for children answer a series of questions which would reveal their understandings of night and day and share the stories they knew about night and day.

Materials-Their Properties and Uses: *Natural and Processed Materials*

The camping theme was continued in the second set of interviews on *natural and processed materials*. An additional story book was made as the main instrument for eliciting Aboriginal children's understandings of natural and processed materials. This story focused on the materials that were needed in order to go camping, the setting up of the camp site, followed by a storm which destroyed all the materials and equipment. This story set the scene to talk to children about which natural materials available in the bush could be used for setting up their camp.

Light: *Energy and Change*

The third set of interviews also made use of the camp scene. The darkened environment was utilised for finding out children's understandings of light. In this interview, each child was invited into the camp scene and on settling, the lights were turned off. The child was asked "What has happened?" "What can you see?". The child was then asked a series of questions in order to determine their understandings.

Intuitive Taxonomies: *Life and Living*

The instrument used to elicit children's understandings in this area was essentially a meter square laminated sheet where major topographical features of the area familiar to the children were drawn upon. Plastic animals and wooden blocks were provided in addition to a range of three centimetre square laminated pictures of a variety of animals, plants, and processed materials such as a tin can. Children freely drew and placed items all over the base sheet. On completion, children were asked to talk about what they had done and why they had chosen to place certain items together. Children were also asked to put the items on the base sheet into groups in a further attempt to find out how they were classifying things.

CONCLUSION

The pilot study provided a range of useful data for analysis. In all areas except the children's recall of traditional stories, richly contextualized data was collected. It was felt that the children's young age and not the questions themselves about traditional stories was the limiting factor. The age factor variable is yet to be examined closely. Children older than eight will be interviewed using the story book on night and day to determine if it will successfully reveal any traditional stories they know, and this data will be analysed to see if the stories influence their scientific understandings of night and day. Overall the study aimed to develop a research design and instruments that would readily tap into young Aboriginal children's scientific understandings in a relevant and cross-culturally sensitive way. The richness of the data collected would indicate that this aim has been met. The next step will be to determine the significance of the data collected and whether data should be collected from a larger sample of young Aboriginal children in each of the community contexts described by the NAEC (1985): Traditional, Rural, Urban Dispersed and Urban.

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Research in Science Education, 1994, 24, 373-374

IMPLEMENTATION OF SCIENCE AND TECHNOLOGY K-6 IN RIVERINA SCHOOLS

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RESEARCH NOTE

The NSW Science and Technology syllabus was released for implementation in primary schools in 1991. The combination of science and technology in one syllabus created a very different key learning area, in a part of the curriculum which many reports have shown teachers already lack confidence in both content and teaching approaches. Within the Riverina region of NSW, the author, together with the regional science consultant, developed a five module training package (completed by every school) and a range of courses available throughout the region as a total implementation plan. Key aspects of the plan included:

* courses of an extended time as 2 or 3 phased programs to allow for input-action-sharing-reflections sequences. This provided all teachers in the region with a minimum of 10 hrs and up to 18 hrs of formal professional development
* courses having significant hands-on components and dealing with the materials in a modelling way
* a system of facilitators to deliver the training package, which created a group of contact people for teachers and a network of people for the consultant to work through
* programs were usually run in a school setting by teachers or a consultant
* identifying both content and methodology as key areas for development
* support by a consultant for three years
* some accreditation into a University subject

This approach was used because most studies have shown that extended periods of reflection and sharing of ideas is most likely to have an effect on implementing a new syllabus. The program with all its facets operated during the period 1991-93. In 1993 the regional office employed the author to evaluate the implementation of the syllabus by teachers. This was done through the use of a survey sent to 30 schools in the region and asking for three teachers, over the range K-6, to fill out the survey.

RESULTS

The survey provided, amongst other things, the percentage of teachers who indicated they had a fair amount or a lot of confidence in the six content strands of the syllabus and the three key processes. These results are shown below. The figures in parentheses are from a similar study by Skamp (1991) of teachers in the NSW North Coast region.

Syllabus Components	% Confident
Information & Communication	63 (55)
Built Environment	62 (52)
Living Things	90 (87.5)
Products & Services	57 (40)
Natural Phenomena	82 (62.5)
Earth & Surroundings	88 (85)
Investigating Process	55 (70)
Design & Make Process	47 (42.5)
Using Technology Process	34 (45)

In comparison with data collected from teachers in other regions in NSW at the time the syllabus was released (Skamp, 1991; Ferry, Harper & Wilson, 1993), Riverina teachers had showed a significant shift in their content confidence. Confidence in using the processes, particularly those associated with technology, failed to show any gains. Other results from the survey found the following:

- teachers found the new syllabus document useful, clear and appropriate;
- teachers found the implementation package a useful professional development activity in terms of its content and structure;
- the Riverina implementation plan led to an increase in confidence of teachers in the content areas, all teachers surveyed were teaching from the syllabus and they were spending more time teaching it;
- there was not a significant shift in confidence about teaching the 3 key processes
- it was evident that teaching practices and management structures appropriate for teaching the philosophy of they syllabus were not being employed.

DISCUSSION

There was evidence in the evaluation that Riverina teachers had made positive shifts in what they were teaching (declarative knowledge). However, when teachers are asked to implement a new curriculum, they are expected to change how they teach (procedural knowledge). Despite considerable emphasis in this area in the professional development programs, the evidence showed that teachers had not gained significant confidence in teaching the key processes, the area of teaching related to how they teach. This supports others (Wallace & Louden, 1992) who had indicated that the fundamental problem with primary teachers and science and technology teaching is not really about content confidence, as constantly reported in the literature, but with expectations about how it is taught and the conflict this has with their existing routines and management structures. Non adoption of new practices has been shown to be a rational process (Vanclay, 1994). It is argued that the logic and message of the change is rationally processed, weighed up in terms of other imperatives (time, other curriculum areas, administration, control, self esteem) and either consciously not taken up, or interpreted and converted into a more familiar pattern.

The key implication of this evaluation is that, if we want to change how teachers teach in any future curriculum implementation programs, more account of within school and within classroom support needs to be put in place. Such support in the workplace should draw on a workplace learning model (NBEET, 1994), in addition to any system wide external support programs.

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Research in Science Education, 1994, 24, 375

ASSESSMENT IN THE SCIENCE CLASSROOM.

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ABSTRACT

This paper reports on research into two teachers' views and practices about assessment at the classroom level. Emphasis was given to practical work and its assessment. Findings suggest it is unhelpful to define practical work as distinct from other activities in the science classroom. Various methods used for assessing activity within the participant teachers' classrooms are described. The participant teachers were found to be primarily concerned about issues of 'fairness': task validity, reliability of assessment based on co-operative work and assessment of the affective domain. The place of teacher intuition in assessment is raised and briefly discussed. Directions for the ongoing research are foreshadowed.

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THE RELEVANCE OF THE TERM 'MISCONCEPTION'

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RESEARCH NOTE

In the 1950s and 1960s the general model of science education was based on enquiry, greatly reinforced by people like Schwab (1962). The treatment of science as enquiry was a means to clarify and illuminate scientific knowledge. This meant there was a body of knowledge to be learned and basically this could be done through enquiry, by making careful observations and generalising to form laws and theories. Dissatisfaction with this method was noted by some workers as some what fraudulent, since it painted a picture that real discoveries were being made by the school students in science (Winchester, 1989). The influence of Popper and hypothetico-deductive reasoning was an event which changed the way scientists viewed scientific method. This has also made untenable some of the central assumptions of the teaching of science as enquiry (Matthews, 1989) or as inductive based learning.

Hypothetico-deductive scientific method

The acknowledgment of the problem of induction by Hume (1939 in Chalmers, 1978) was further discussed by Popper (1968) who advocated the hypothetico-deductive method. The hypothetico-deductive model (Fig. 1) represents that for any particular series of observations that one has made, there will be usually more than one model or explanation. Thus some procedure is necessary to distinguish among various often contradictory alternative explanations. Only when the alternatives have been subjected to critical examination leading to the failure of some will the remaining ones be seen as possible valid explanations. There are, almost invariably, competing explanations that could explain the observation (Chamberlain, 1890/1965). The falsificationist procedure is advocated to distinguish among them to eliminate the model which is false. The procedure advocated is to use each explanation as a starting basis for the construction of an hypothesis or prediction. Having arrived at the hypothesis it is necessary to subject it to a test. Because of the ease of disproving something, instead of testing the hypothesis an alternative null hypothesis is created. Rejection of the null hypothesis gives support to the original explanation.

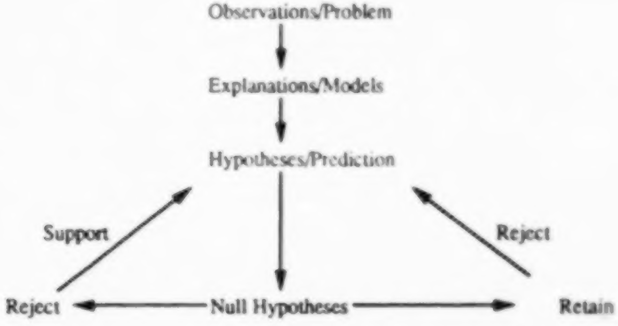

Fig. 1 Hypothetico-deductive method (Underwood, 1991)

Alternatively, support of the null hypothesis leads to the rejection of the explanation (Underwood, 1991). In the hypothetico-deductive model it does not follow that the model which has not yet been rejected is the correct model, only that it is still one of the possible valid models. It does however mean that an explanation can be tested and refined to become more complex. The end-point the scientist reaches using a hypothetico-deductive method is a supported explanation which describes a pattern; this explanation or model is the 'survivor', the result of rigorous testing and the best conception the scientist has, but this 'best conception' will be a 'misconception' in time. Students who arrive at the presently held scientists view do not have a misconception, as defined in the scientific education literature. Those students who do not arrive at the scientists view have a misconception. One part of the process of science is that science knowledge is dynamic (always a misconception). Failure to characterise scientific knowledge as tentative is an inaccuracy in science teachers and science educators work (Gallagher, 1991). One part of the process of science is that science knowledge is dynamic (always a misconception). Science educators need to portray science as temporary, but supported knowledge.

What is science at school?

Studies of classroom practice in the United States have presented science as revealed truth with emphasis placed on the body of knowledge, but with little presentation of how science is formulated or validated (Gallagher, 1991). My observations are that the language and terminology (e.g. verify, conclude, prove etc.,) used in "practicals" largely reflects the inductive view of science. Students are rarely asked to reject a null hypothesis to give support to a hypothesis and thus an explanation. One explanation of this is that teachers view science as inductive. My research is on the testing of this explanation in New South Wales secondary schools.

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Research in Science Education, 1994, 24, 378-379

THE EFFECT OF INTERVENTION STRATEGIES ON CREATIVE THINKING SKILLS OF PRE-SERVICE TEACHERS.

Roy Skinner, William Foulds & Judith Cousins
Edith Cowan University

RESEARCH NOTE

Creativity

Science education has not traditionally fostered creativity yet it lends itself to imaginative problem-solving and inquiry. This research note presents the results of a study where a group of pre-service teachers were exposed to creative thinking strategies within their normal science education course. Preliminary findings from this research indicate the value of these creative thinking strategies in improving self-concept, verbal fluency and originality of ideas. The development of creativity is valued as a broad educational goal yet little appears to be done in tertiary courses to specifically develop creative thought patterns in our trainee teachers. School science and technology curricula have the potential to develop and utilise creative and critical thinking. However, many would question the effectiveness of cognitive skills development in science at the moment. Williams (1972) defines creative thinking behaviours as fluency (the ability to generate many ideas), flexibility (the ability to generate different classes of ideas), elaboration (the ability to build on existing ideas) and originality (the ability to generate novel ideas). In addition, he also proposes important feeling behaviours necessary for the efficient production of creative thought as risk taking (willingness to move to unknown regions), curiosity (willingness to explore), imagination (willingness to think of what might be) and complexity (willingness to take on a challenge). These characteristic creative thinking and feeling behaviours form the basis of the many tests developed to identify and measure creativity (Wakefield, 1991). For this study three such tests were used to see if the creative thinking strategies incorporated into the course were able to increase he measured creativity of the experimental group. The three tests used were the TCT-DP drawing test (Urban & Jellen, 1986), the IOWA Creative Thinking Assessment Model (Yager, 1991), and the Creativity Inventory (Williams, 1972).

Methods and results

A cohort of first year pre-service primary teachers was pre-tested and divided into an experimental and a control group, with all six classes receiving the same basic science education course for the semester. In addition, the experimental group also received instruction in the use of selected creative thinking strategies. In the last two weeks of the semester the three tests were administered again to the cohort as a post-test. The results of the t-test comparisons between the experimental (E, N=52) and control (C, N=49) groups for the three creativity measures are shown in Table 1.

Summary and discussion

For two of the three measures of creativity used in this research it can be seen that there were statistically significant gains made by the experimental group which are inferred to be a direct result of the creativity intervention strategies employed. For the IOWA test, the large increase in the numbers of Unique Responses (110%) supports the hypothesis that intervention strategies do enhance creativity. The findings for the third measure (TCT-DP) are not consistent with those of the other two measures: the gain in scores was small and not statistically significant, while the control group displayed a large and significant gain. In order to explain the unexpectedly large increase in TCT-DP scores by the Control group one would need to know how strong the influence of the 'Lecturer' variable was compared with the 'Intervention' variable. Appropriate classroom environments are also recognised as a key factor in producing creative behaviour (Walberg, 1987). At present this comparability is largely unknown. Creativity Inventory tests given to the lecturers, themselves, indicated that the

TABLE 1
SCORES OF EXPERIMENTAL AND CONTROL GROUP ON THREE TESTS

TEST	GROUP	PRETEST	S.D.	POSTTEST	S.D.	PROB.
Creativity Inventory	E	66.3	10.0	71.3	8.6	0.003
	C	65.9	9.6	67.3	11.4	0.225
IOWA test, unique responses	E	1.00	1.3	2.10	2.5	0.002
	C	1.28	1.8	1.77	1.9	0.090
TCT-DP	E	24.0	9.7	25.6	9.1	0.200
	C	21.6	6.6	28.0	11.4	<0.001

lecturer for the Experimental group had a higher creative self concept than either of the two Control group lecturers. More is required than just creativity intervention strategies to enhance creative thought - students must feel that the class environment is such that they are **allowed** to be unconventional or to break rules or to express different opinions to the 'correct' scientific ones (Goodlad, 1984). The Control group lecturers, whilst not providing specific thinking skills training, seem to have established within their classrooms an ethos which encourages a higher self-concept in their students, although this was not clearly evident from the Creativity Inventory scores. Anecdotal evidence supports the notion that although creative thinking strategies were utilised within the Experimental group's classroom the lecturer was not prepared to break away from the more traditional rigour of science delivery. This seems to have given students conflicting messages about their freedom of expression and their feelings towards the subject of science seemingly reflected this in the picture-drawing test. It appears that it is possible to raise the levels of creativity through the use of creative thinking strategies. However, creativity interventions, by themselves, are not sufficient to enhance all aspects of creative thought without an accompanying conducive classroom environment.

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Research in Science Education, 1994, 24, 380-381

OBSERVATIONS FROM THE CLASSROOM: WHEN ANALOGIES GO WRONG!

David F. Treagust, Susan M. Stocklmayer, Allan Harrison,
Grady Venville & Rodney Thiele
Curtin University of Technology

RESEARCH NOTE

Analogies and learning

Research, as well as teacher self-reports and anecdotal evidence, indicates that analogies have much potential to enhance learning. However, the use of analogies is fraught with difficulties when due consideration is not taken concerning the essential aspects that make up an analogy. To address this issue, we have been working with a cadre of teachers in Western Australian schools who are interested in improving their analogical teaching. In doing so, we have used two models, firstly a modified Teaching-with-Analogy model derived from the work of Glynn (1991) and secondly the FAR Guide to analogy teaching (FAR being an acronym for Focus, Action and Reflection as being the features that need attention when the analogy is being taught, Treagust, 1993). With or without these models to help enhance learning with analogies, we have observed teaching episodes where analogies simply did not work. In this note, we have illustrated how these analogies do go wrong. By focussing on those features where analogical instruction breaks down, it is possible to provide further guidance to science teachers about the careful use of analogies rather than simply dismissing them as a source to enhance learning.

Research on difficulties with analogies

The teaching-learning episodes described in this note come from more than 100 lessons. The episodes involve teachers' verbal explanations and use of textbooks related to some aspect of analogy instruction taught in general science in Years 8, 9 and 10, and chemistry, physics and biology in Years 11 and 12. We report several examples of episodes that were not as successful as intended by the teacher and have categorised them under five, non-exhaustive headings. Subsequently, analogies go wrong when:

1. Students attend to observed or imaginary functional attributes of a structural analog. For example, several Australian chemistry textbooks describe an analogy of a marble on the MCG to depict the nucleus of an atom. The key aspects of the analogy relate to the sharing of structural rather than functional attributes and the concrete analog attempts to describe an abstract science concept. Several students expressed their understanding of the atom in terms of the functions of imaginary attributes - the players - of the analog which were not part of the intended analogy.

2. Students lack familiarity with the analog concept. Analogs which are familiar to students are more likely to be fruitful in terms of enhancing conceptual understanding than those which are not. In situations where a suitable analog is not familiar to the students, explaining the analog may rectify a situation where analogies may otherwise go wrong.

3. Students and teacher hold an objectivist view of the nature of science. Analogies are best used in a classroom environment which teaches science not as true facts, but as theoretical interpretations subject to falsification. In this environment analogies are more likely to be seen as metacognitive tools with which students can make sense of the phenomena under discussion rather than exact representations of scientific facts.

4. **Teachers are using analogies to teach concepts outside their area of expertise.** Problems in the mapping of shared attributes between the analog and science concept and in the identification for the students of unshared attributes between analog and science concept seems most likely to occur when the teacher lacks a clear conceptualisation of the concept being presented.

5. **Analogies lack sufficient conceptual depth.** For example, when students mapped the bridge over a valley as analogous to a catalysed chemical reaction, one student commented that she knew that a catalyst provided a path for lower [activation] energy, but still did not know how the reaction worked. Clearly, in a search for a more conceptual understanding, possibly at a molecular level, this student found the analogy lacking conceptual depth.

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FIRST YEAR UNIVERSITY SCIENCE - REVISITED

Petrus Zeegers
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RESEARCH NOTE

Introduction

Not all new students come to university equally well prepared. The inherent difficulties associated with the transition to tertiary study may be further exacerbated when assumptions are made by the teaching staff as to the level of preparedness of their students. This is particularly the case for those students who have gained entrance to university Science courses by means other than the traditional route. Recent work has looked at the difficulties encountered by first-year students of Arts, Science, Law and Commerce. The results of the studies found that the problems most often experienced by the students, though numerous and diverse, can be classified into six broad categories: academic preparedness, academic progress, personal, family, financial and social. The present study is concerned only with the academic issues, though the other factors may also impinge on the issues in that area.

Methods

The aim of this study was to ascertain the problems faced by new students of Science when they first enter the tertiary system. What subjects do they find the most difficult ? Which do they find the least difficult ? What are the major problems that new students encounter when they first enter the university ? The answers to some of these questions will help to formulate the role of my position in providing academic support. The second aspect of this study was to look at what strategies can be utilised to minimise the problems and possibly overcome them. The long term goal is to minimise the high first-year Science drop out rate and to allow each student progress through their chosen course in the minimum of time.

For the present study, two groups of commencing Science students were readily identifiable and were selected as being representative of first-year university Science students at Flinders University. The two groups are differentiated by their Science backgrounds which is evident by their choice of first year Science and Mathematics subjects. These two groups are labelled Groups A and B for convenience.

Group A consists of those choosing to study Science at university without the "traditional" high school Science and Mathematics background. It contains students who have recently matriculated (58%) but have not studied Science and Mathematics subjects. It also contains those students (42%) who have entered the university through mature entry schemes, through a foundation course or by means of a special entry scheme for non-matriculants. All group A students were enrolled in at least one of the introductory Science or Mathematics subjects.

Group B contains the traditional first-year Science students, having studied Science and Mathematics to Matriculation level.

The results were largely used to determine my own approach to providing academic assistance to the students. The results were also used to set in train strategies to enable teaching staff to teach their students more effectively and to enable the students to become more effective learners.

Summary

Compared to the other two South Australian universities, Flinders University attracts a greater proportion of undergraduate students who are older, who come from a wider range of educational backgrounds, who come from a lower socio-economic background and who may be less academically prepared to handle the tasks demanded of them. In the area of the Sciences these students are distinguishable from the more traditional first-year Science students though the problems they face have a degree of similarity. This cohort of students is generally attracted to the study of the Biological Sciences and have to some extent tended to avoid the study of subjects with a mathematical component. All commencing Science students however have difficulties adjusting to the new world of tertiary study. Some adapt readily but many do not. This is evident by the high failure rate and the withdrawal rate of many first year subjects. The high attrition rate of Science students is also evident in the low graduation rate figures derived from statistics kept by the university. This latter evidence suggests that less than half the students in the Sciences attain their degree in four years (1990 statistics). Much of this stems from problems encountered in the first years of a degree program.

Six key areas of difficulty are faced by commencing students at tertiary institutions in South Australia. Of these the two most directly related to this study are the issues of academic preparedness and academic progress.

This study has focussed only on the student centred problems and has not tackled the more vexed problem of tertiary teaching. As such it has concentrated on providing the students with some of the academic skills required to be successful tertiary students.

As a result of this study, and subsequent follow up work, the following list of strategies have been implemented by the author or are proposals for future implementation:

- a comprehensive academic orientation program for all commencing Science students which specifically addresses some of the concerns of students;
- a comprehensive handbook for commencing students outlining the essential skills necessary for a student to successfully study Science at a tertiary level;
- peer group study for students with difficulty in specific subjects or areas;
- close liaison between faculty teaching staff and academic advisers;
- targeting 'at risk' students or students with special needs as identified by teaching staff;
- a continual program of academic skills seminars taught within the mainstream discipline subjects as the need arises;
- close liaison between the secondary schools and the tertiary sector;
- bridging courses to bring students up to the required level, particularly in the area of mathematics.

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Research in Science Education, 1994, 24, 385-388

SUPPLEMENT

THE BOOK OF GENESIS AND THE CHRONICLES OF THE PEOPLE OF ASERA*

Dearly beloved, we are gathered together in the sight of the Great Vice-Chancellor and all this company to celebrate this holy festival, for as it said in the Book of Genesis and Chronicles of the People of Asera, Ye shall assemble the people of Asera, even all the tribes, from the tribe of Curtin in the west to the tribe of Waikato in the east, and ye shall have a holy convocation, and ye shall eat, drink and be merry, and read the words of this book, all the days of your life.

Let us pray.

In the beginning, the Great Vice-Chancellor created the heaven and the earth. And the earth was void and without form, and darkness reigned upon the face of the deep. And so the Great Vice-Chancellor created greater lights called universities to rule by day, and lesser lights called CAEs to rule by night. And the Great One saw that it was good.

But the lands were empty and devoid of life. And so he created tutors and research assistants and Ph.D. students and other endangered species. There were northfields, and trees with appletons, and evolution occurred with missing linkes. And the Great One saw that it was very good.

But it was not good for these forms of life to dwell alone. And so the Great One took a rib from a tutor, a backbone from a research assistant, and a brain from a Ph.D. student, and created the first academic, whose name was Methusaleh. And Methusaleh lived for nine hundred and sixty nine years, and published nothing, and his tenure was revoked and he was given early retirement.

And the Great One caused a flood of knowledge to wash over the earth, and so he created an A.R.C., or ark, to protect his creatures.

And the Great One created linguistic confusion on the earth, a veritable tower of psychobabel. He caused the Romans to write from left to right, the Hebrews from right to left, the Chinese from top to bottom, and Peter Fensham all over the place.

[* Editor's note: This sermon was given at the annual dinner in Hobart by a theologically confused gentleman wearing a bishop's mitre, a cardinal's cloak and a rabbinical beard. He insisted that it be "circulated in the Chronicles to all the tribes of ASERA". I promptly rejected it as a paper, pointing out to him that it added absolutely nothing to the field of science education research, that it had not been reviewed, that his literature review was very skimpy, and that no references in APA format had been included. He threatened me with divine wrath. I then proposed to publish it, using his own language, "looseth leafeth", but he refused to agree to this, citing the first Almighty Editor's precedent, which he considered quite unsatisfactory. We finally settled on this supplement, and he went off, muttering assorted fragments of Gregorian chants, the Hallelujah Chorus, psalms and Talmudic texts, not happy, but at least fairly calm. I never saw him again. P.L.G.]

But this Peter was a wise and gentle man, who knew both the science of chemical bonding and the art of human bonding. And the Great One said unto him, Go, remove thyself from the dungeons of Melbourne to the rockpile of Monash. For thou art Peter, and upon this rockpile I will build a great temple of science education, and the people of Asera will worship therein, and will be fruitful and multiply. And they will write many papers, and use up many trees, even all the cedars of Lebanon, yea, even all the trees of the Sahara Forest.

But know too that when thou leavest thy house, and goest abroad, thou shalt not walk upon water, but shall fly with wings, for as it is said, He who walketh upon water collecteth no frequent flyer points.

And the apostle Peter smiled upon his servant Lindsay the son of Mackay, and said unto him, Go thou and collect together the names of the children of Asera. And the Great Vice-Chancellor built a holy temple with a great machine, and Lindsay bowed in awe before it, and punched holy cards, and he sent his maidservants to carry the cards to the Temple, whereupon the machine growled and chewed up the cards and printed out the names of the children of Asera. And this list existeth to this day. And Peter called a meeting, saying, Come, let us reason together, so that the tribes of Monash and Macquarie and Queensland and Tasmania can unite together into a single nation, great, mighty and populous.

And the people came from far and wide, from the four corners of the earth, and had an annual holy convocation. And so began many years of wanderings of the people of Asera, from the centrally located, marvellously cosmopolitan city of Melbourne, that Garden of Eden, with its perfect climate, outstanding restaurants and sophisticated population, to all the other less endowed corners of the land. They wandered to the city of sin, where David, the Cohen, the High Priest of Macquarie dwelled. They wandered further north, to the Land of Cane, where there were cane-toads. They wandered to the mid-west, to a land where the Labor Party swallowed uppers when they were down, and the Liberal Party swallowed Downers to get up. They wandered further west, to a land of unamalgamated universities and amalgamated un-universities. They wandered to the islands of kiwi-fruit and sheep to the east, where the people ate fush and chups, sex times a week. And they even wandered to the island of Sodom and Gomorrah in the south. And the Great Vice-Chancellor commanded the people, saying, in the seventh month, in the second week of the month, assemble the people of Asera, for it shall be unto you a wholly satisfying convocation.

And there arose among the tribe of Queensland a prophet, a wise man, Richard the son of Tisher, who had a dream, and prophesied that the people of Asera would one day prepare annual Chronicles. For he said, what shall it profit a man that he speaketh, and his words are recorded not? What gain shall there be for a woman who writeth, yet scoreth no points in the Great Vice-Chancellor's Quality Assurance Program? And he said, Publish it not in Gath nor in Ashkelon, but in Brisbane, and he offered himself before the people as their humble servant.

And the people of Asera listened to Tisher, and acclaimed him, and danced around him with great joy and wonderment, and proclaimed him Editor of the Chronicles. For as it is said, he who openeth up his mouth to volunteer soon wisheth that he had kept it shut. And yet the people of Asera were unsatisfied, for they cried out to him, Almighty Editor, write down your words of wisdom and we will sing them as a song of exultation, all the days of our life. And so Richard the son of Tisher sat for forty days and forty nights in his tent in the desert of St Lucia, neither eating, nor drinking nor playing golf, and thought about the trends in science education, and wrote down the words of the first Chronicles.

And the prophet came out of the desert, and gave the Chronicles to the people of Asera. And yet the people were unsatisfied and demanded more. And so Richard the son of Tisher wrote an Editorial Preface, and prophesied that a day would come when there would be an annual journal of Asera. And he sent out the Chronicles, but forgotteth to print the Editorial, and includeth it afterwards, looseth leafeth.

And Richard sighed and groaned under the labour. And the Great One heard his cries, and sent him to the southland to profess his faith. And Richard relieved himself, of his work as Chronicler.

Now there arose in the tribe of Monash another Richard, servant to the apostle Peter, whose star waxed in the firmament of heaven, for he rose from administrative assistant to the apostle, to Ph.D. student to lecturer to senior lecturer to associate professor to professor to Dean, displaying a hierarchy of learning. He was a tall man, and the height thereof was two cubits, and the Great One spoke unto him saying, Many servants of mine have done worthily, but verily thou art the longest Dick of them all.

And it came to pass that a new Pharaoh arose, a higher Power, a Colin of the tribe of Flinders, who became Almighty Editor of the Chronicles. And Pharaoh Colin had a terrible dream, and he dreamt of figures dancing and falling over. And none in his kingdom could decipher it, save only his butler who could interpret his dream. And the butler said unto Pharaoh, the figures are the income and expenditures of the Chronicles, and their falling over is due to their inability to balance. And so the Pharaoh made Jim Butler his business manager. And Pharaoh had another dream, of chateaus and Eiffel towers and can-can girls. And he followed his dream, and left the tribe of Flinders for Paris, from the insane to the Seine, and the children of Asera knew him no more.

And there arose in the tribe of Monash a young Fraser, for he was indeed adept at phrasing, for he knew the art of saying the same words in different ways, each counting as a separate publication. And he wrote a paper for the Chronicles on The Impact of ASEP on Pupil Learning and Classroom Climate. And one of his memorable phrases was:

> The equation may be expanded to yield seven sets of predictors of learning:
>
> $$L_{h} = f_1(I_i) + f_2(A_j) + f_3(E_k) + f_4(I_iA_j) + f_5(I_iE_k) + f_6(A_jE_k) + f_7(I_iA_jE_k)$$

To which another Fraser of the time responded, Life wasn't meant to be easy.

And the tribe of Monash honoured the young Fraser with a hooded garment of finely woven scarlet silk, and praised him mightily, and sent him westwards as quickly as possible.

And it came to pass in the island to the east that a prophetess arose, Beverley from the tribe of Waikato, whose voice was like a bell, yet she wrote with a LISP. And she divined children's thoughts and constructed their meanings, and came into conflict with St. Matthews from the land of the Aucks who deconstructed constructivism and said it maintained an Aristotelian-empiricist paradigm, and called for much epistemological imbibing of new philosophical wine, and other lewdness. Whereupon the prophetess Beverley stood forth at the annual holy convocation and delivered a well-directed stream of feminist empiricist post-modernism. And St Matthews retreated to the land from whence he came, and his gospel was heard no more in the land of the Aucks.

And now there arose a new Editor in the land, the apostle Paul. And he climbed the holy mountain to commune with the Great One, and came down from the mountain bearing two tablets of stone, size A4, 90 characters per line, 50 lines per tablet. And the people were hushed, and they prostrated themselves as they heard these words:

> **I am the Almighty Editor, who brought thee out of the land of electric typewriters into the land of laser printing.**
>
> **Thou shalt not make any graven images using dot-matrix printers and worn-out old printer ribbons.**
>
> **Honour the length requirements of thy Chronicles, for the Almighty Editor is a ruthless Editor, and in remembrance of the covenant with our father Abraham will circumcise thy work if it groweth too long.**
>
> **Remember the day of Judgement, one month after the conference, for the Almighty Editor is a stroppy editor, and will not hold thee guiltless when thou submittest thy work late.**
>
> **Thou shalt not murder the English language.**
>
> **Thou shalt not steal the ideas of others, without proper referencing.**
>
> **Thou shalt not adulterate thy text with split infinitives, misplaced apostrophes, misuse the word 'methodology', or use 'trial' as a verb when 'try out' is meant, nor do anything which will offend thy Editor.**

And it came to pass that one day a shepherd was tending his flocks by the Dead Sea, which is Port Phillip Bay, and he encountered a cave, and it contained a dusty parchment containing many words in an ancient tongue. And he took the parchment to the elders of his tribe, who deciphered the words, and Lo! they were the lost words of Richard the son of Tisher, in the first Chronicles. And the elders took the words to the people at their holy convocation, and the people rejoiced, and sang a great song of exultation, and their hearts were satisfied at last, and they bowed down and praised the Great One and all the apostles, prophetesses, saints and almighty editors:

> *The objectives of this paper are to refer to some trends in science education and to suggest several implications for research. Amen. An attempt will be made to specify a number of research questions, and to indicate the types, or styles, of research which may be used to answer the questions. Hallelujah. In addition, it is proposed to raise four important issues which are of concern to all science education researchers. Amen. It will not be possible, in the time available, to describe in detail some research designs. Hallelujah. However, it may be possible for groups to meet to discuss the designs of future projects. This issue will be raised again later.*
>
> *Tisher (1971).*

[Editor's Note: At this point, the clerical gentleman made his exit, to the sounds of heavenly voices singing 'Amen'.]

ASERA EDITORS

1971-73	Richard P. Tisher
1974	Richard P. Tisher, Russell D. Linke & Leo H.T. West
1975	Colin N. Power & A.N. Lucas
1976	Colin N. Power & M.N. Maddock
1977	Colin N. Power & Anthony D. Blake
1978	Colin N. Power & Campbell D. McRobbie
1979	Colin N. Power & Denis Goodrum
1980	Colin N. Power
1981-82	Laurie Rattray-Wood & Peter Ferguson
1983-88	Richard P. Tisher
1989	Richard P. Tisher & Paul L. Gardner
1990	Paul L. Gardner
1991	Paul L. Gardner, Helen Forgasz & Jeffrey R. Northfield
1992-94	Paul L. Gardner

ASERA CONFERENCES

1970	Melbourne
1971	Sydney
1972	Melbourne
1973	Brisbane
1974	Melbourne
1975	Adelaide
1976	Newcastle
1977	Wagga Wagga
1978	Brisbane
1979	Perth
1980	Melbourne
1981	Hobart
1982	Sydney
1983	Hamilton, NZ
1984	Melbourne
1985	Rockhampton
1986	Adelaide
1987	Wagga Wagga
1988	Sydney
1989	Frankston
1990	Perth
1991	Gold Coast
1992	Hamilton, NZ
1993	Lismore
1994	Hobart

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